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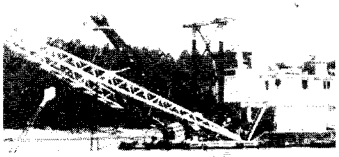

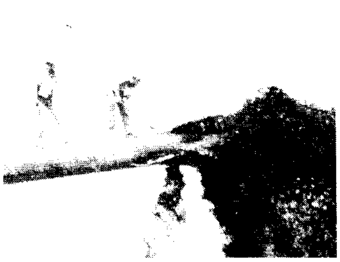

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FEASIBILITY OF USING MYCORRHIZAL FUNGI FOR ENHANCEMENT OF PLANT ESTABLISHMENT ON DREDGED MATERIAL DISPOSAL SITES: A LITERATURE REVIEW

by

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Establishment of vegetation on dredged material disposal sites is often essential for stabilization of the deposited material and for enhanced beneficial uses of dredged material (e.g., habitat development and reforestation). However, desirable vegetation frequently is exposed to low nutrient availability, inhibitory levels of toxins, and unsuitable moisture conditions. Commercial fertilizers may ameliorate nutrient conditions, but applications of

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fertilizers at initial planting and at subsequent intervals may be difficult logistically and costly. Detoxification of dredged material can require longer periods of time than are acceptable for the desired stabilization or reclamation of the site with vegetation. Moisture deficiencies are sometimes a problem when water drains rapidly from a sandy disposal site. Abundant evidence from reforestation, reclamation of strip-mined sites, and agriculture suggests that all of these problems are potentially amenable to solution by the use of mycorrhizal fungi.

Mycorrhizal fungi are one of the most extensively occurring groups of beneficial soil microorganisms. Few plants lack them. Mycorrhizal fungi form an intimate mutualistic association with plant roots (mycorrhizae) that extends the absorptive area of the roots (sometimes thousands of times) and contributes greatly to mineral nutrition, water absorption, and root system stabilization of the host plant. Beneficial effects of using mycorrhizal tree seedlings are so profound that the US Forest Service established a special research facility in 1977, the Institute of Mycorrhizal Research and Development, at Athens, Ga., to study the occurrence and beneficial uses of mycorrhizae on conifers and hardwoods. The Institute is presently engaged in efficacy testing of commercially produced mycorrhizal spore formulations. Researchers at the Institute have found that mycorrhizae are capable of increasing growth rates 2- to 80-fold in hardwood seedlings.

The literature documents increased plant tolerance to adverse or toxic soil conditions by mycorrhizal plants in revegetation of strip-mined sites, kaolin spoils, iron tailings, and processed oil shale. Mycorrhizal plants are consistently more successful in these areas, sometimes exhibiting shoot dry weights 1370 to 1528 percent higher than nonmycorrhizal plants. Not only do mycorrhizae contribute to plant success in adverse substrate conditions, but also have been shown to sequester and store certain heavy metals, thereby detoxifying soils.

The extensive external mycelium together with an amorphous polysaccharide secretion are a dominant factor in the aggregation of soil particles by mycorrhizal plants. The effectiveness of these two mechanisms is especially evident in stabilization of sand dunes. These same mechanisms, assisted by additional absorption mechanisms, account for increased soil moisture retention and enhanced water availability and uptake by host plants.

This literature review discusses the potential role of mycorrhizal plants in the development of upland, marsh, and aquatic habitats. Tremendous potential exists for enhancing the establishment and growth of vegetation on upland dredged material disposal sites with mycorrhizae. Although much less is known about the mycorrhization of marsh plant species, the limited research available suggests that use of mycorrhizae has some potential for enhancing establishment and growth of marsh plants on dredged material disposal sites. Very few studies of the mycorrhizal status of aquatic plants were found; therefore, the potential for using mycorrhizae to enhance development of aquatic habitat is not known.

PREFACE

This is a literature review initiated to determine the feasibility of using mycorrhizal fungi for enhancing the establishment of vegetation on dredged material disposal sites. The study was sponsored by the Dredging Operations Technical Support (DOTS) Program funded by the Office, Chief of Engineers, through the Water Resources Support Center, Dredging Division (WRSC-D). DOTS is managed through the Environmental Effects of Dredging Programs (EEDP) of the Environmental Laboratory (EL) of the US Army Engineer Waterways Experiment Station (WES). Mr. Charles C. Calhoun, Jr., was EEDP Manager at the initiation of the study; Dr. Robert M. Engler was EEDP Manager during publication; and Mr. Thomas R. Patin was DOTS Coordinator in EEDP. The work was monitored by Mr. David B. Mathis, WRSC-D.

Mrs. Judith C. Pennington of the Wetland and Terrestrial Habitat Group (WTHG), Environmental Resources Division (ERD), EL, WES, conducted the literature search and prepared this report. The review was conducted under the technical supervision of Mr. Edwin A. Theriot and Dr. Dana R. Sanders, Sr., WTHG; under the direct supervision of Dr. Hanley K. Smith, Chief, WTHG; and under the general supervision of Dr. Conrad J. Kirby, Jr., Chief, ERD, and Dr. John Harrison, Chief, EL. The report was edited by Ms. Jamie W. Leach of the WES Publications and Graphic Arts Division.

At the time of publication, COL Allen F. Grum, USA was Director of WES and Dr. Robert W. Whalin was Technical Director.

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CONTENTS

FEASIBILITY OF USING MYCORRHIZAL FUNGI FOR ENHANCEMENT OF PLANT ESTABLISHMENT ON DREDGED MATERIAL DISPOSAL SITES: A LITERATURE REVIEW

PART I: INTRODUCTION

Rationale

1. To maintain the navigable waterways of the United States, the US Army Corps of Engineers dredges 300 million cubic yards* of sediment annually. Habitat development for the reclamation of dredged material disposal sites received special emphasis under the Dredged Material Research Program (DMRP), and continues to be important as US Army Engineer Waterways Experiment Station (WES) personnel monitor the long-term ecological status of man-made habitats to determine the most efficient, low-cost stabilization and reclamation methods for disposal areas. Rapid establishment of vegetation on dredged material disposal sites is often essential for stabilization of the dredged material, and for development of beneficial uses (habitat development, reforestation, reclamation, agriculture, and so on).

2. Herbaceous and arborescent plant species often have difficulty establishing on dredged material because nutrient availability is low and microorganisms capable of ameliorating the nutrient status are absent. Addition of commercial fertilizers is usually necessary to satisfy initial nutrient requirements of establishing vegetation, but initial and required subsequent additions are often difficult and costly to supply. Providing plants with a complement of mycorrhizal fungi may reduce amounts of fertilizer required initially, and may sustain vegetation over longer periods of time by stimulating more rapid development of normal rhizosphere microflora.

3. Mycorrhizal fungi are one of the most extensively occurring groups of beneficial soil microorganisms. Very few plant species occur naturally without mycorrhizal fungi associated with their roots. These mutualistic fungi make major contributions to mineral nutrition, water absorption, and root system extension in host plants. In fact, many plants are dependent upon mycorrhizae for survival and growth. The forest industry, agriculture, and

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* 229 million cubic metres.

land reclamation efforts have increased survival and productivity of vegetation by including mycorrhizal fungi in planting programs. Mycorrhizae have also been implicated in increased plant tolerance to adverse or toxic soil conditions, in conferring resistance to plant disease, and in stabilization of substrates.

Purpose

4. The purpose of this literature survey is to determine the feasibility of using mycorrhizal fungi to enhance the establishment of vegetation on dredged material disposal sites.

Objectives

5. The objectives of the survey are to:

a. Review the physical and chemical characteristics of dredged material that are relevant to its revegetation and to mycorrhizal development and benefits.

b. Review problems with vegetation establishment for habitat development on dredged material that may be amenable to solution by mycorrhization of plants.

c. Review relevant factors affecting establishment and growth of mycorrhizae.

d. Review the beneficial uses of mycorrhizae in reforestation, land reclamation, and agriculture.

e. Describe the potential benefits of mycorrhization for establishment of vegetation on dredged material disposal sites.

f. Compile a list of plant species with associated mycorrhizal fungi that would be suitable for use in reclamation of dredged material disposal sites.

Approach

6. Most references used in this report were generated by a computer search of the AGRICOLA (National Agricultural Library) back to 1970, Comprehensive Dissertation Abstracts 1861-Jan 1983, CAB (Commonwealth Agricultural Bureau) 1970-Jan 1983, and Conference Papers Index 1973-1982. Key words sought were mycorrhiza, -ℓ, -e, -s; endomycorrhiza, -ℓ, -e, -s;

ectomycorrhiza, -ℓ, -e, -s; ectendomycorrhiza, -ℓ, -e, -s; actinorhiza, -ℓ, -e, -s; rhizobacteria; root-colonizing bacteria; root-colonizing fungi; soil microflora; and mycorrhizae and -revegetation, -spoils, -roots. Many additional relevant references were obtained from reference sections of journal articles and bibliographies of books. References on dredged material and disposal sites were selected from "Publication Index and Retrieval System" (WES Technical Report DS-78-23) and reference sections of WES technical reports.

7. Common names of plant species were used throughout the text for the convenience of the reader with scientific names added in parentheses when the plant was first mentioned. Occasionally the cited research was of foreign origin and only common or only scientific names were given. In such cases, only the name occurring in the reference was used. Tables were alphabetized by scientific names of plants in order to show the mycorrhizal similarities within plant genera. Although common names are also given in tables, occasional blanks occur where no common names are indicated by authoritative references (Fernald 1950; Long and Lakela 1978; Godfrey and Wooten 1979). Only scientific names are given for mycorrhizal fungi.

PART II: DREDGED MATERIAL

Physical Characteristics

8. Physical characteristics of dredged material that are important to developing vegetation, and potentially important to mycorrhization, are particle size, bulk density, moisture retention characteristics, and extensibility. Each is discussed below.

Particle size

9. Dredged material has particle sizes varying from relatively coarse sand to fine clay. The distribution of variously sized particles (texture) affects many physical and chemical characteristics of dredged material and can exert important constraints on the kinds of vegetation successfully establishing on disposal sites. For example, fine-textured silts and clays provide a large surface area per unit weight for sorption and exchange reactions. Therefore, these materials exhibit a high cation exchange capacity and a high affinity for organic matter, trace metals, pesticides, and nutrients (Yu et al. 1978). These characteristics relate directly to establishment and growth of vegetation by impacting nutrient availability and toxin immobilization.

10. Ideal agricultural soil is loam that is composed of 50 percent or less sand, 40 percent or less clay, 60 percent or more silt (Gupta et al. 1978). Dredged material samples differ greatly in the ratio of clay to sand. In one study, the percentage of sand in dredged material samples varied from more than 50 percent to more than 90 percent (Yu et al. 1978), and in another, more than 30 percent clay was found in four samples of dredged material, 11 to 30 percent in four samples, and less than 10 percent in two samples (Gupta et al. 1978). The ratio of sand to silt is frequently determined by soil texture in the area. For example, an average of 20 percent clay was found in dredged material at a Sayreville, N. J., site, while 24 percent occurred in soils found near the site (Yu et al. 1978).

11. The texture of any dredged material is an important factor in disposal site design. For example, barren, extensively ponded areas are excellent for containment of coarse-textured sediments and for initial containment of fine-textured sediments that are high in clay and silt. However, these are not suitable for continuous discharge and require prolonged periods of

sediment dewatering. Large diked areas of wetland vegetation lacking extensive ponding or high dikes are most efficient for long-term disposal of fine-textured dredged material (Hoeppel et al. 1978). Fine-textured dredged material generally requires some kind of containment, with the requirement becoming progressively less critical as particle size increases (Smith 1978). The types and success of vegetation establishing on dredged material can be greatly affected by the design of disposal sites.

Bulk density

12. Bulk density, defined as weight per unit volume of material, is an indication of the size and arrangement of soil particles. Bulk densities of medium- and fine-textured dredged material were found to be lower (0.67 to 1.24 g/cm^3) than those of productive agricultural soils (1.0 to 1.6 g/cm^3), and bulk densities in very coarse-textured dredged material (1.50 to 1.59 g/cm^3) were similar to those of agricultural soils (Gupta et al. 1978). However, data on bulk densities in dredged material vary. Bulk densities ranged from 1.2 to 2.2 g/cm^3 in a study of four confined land disposal areas in the United States (Yu et al. 1978) and from 0.91 to 1.41 g/cm^3 in dredged material taken from several harbors and lakes in Canada (Mudrock and Zeman 1974). This latter dredged material was high in organic matter that contributes to low densities. No data were found specifically correlating bulk densities of dredged material to plant establishment and growth. However, high bulk densities (not the typical case in dredged material) can make penetration of the substrate by plant roots difficult. It is possible that inoculation with mycorrhizae may be beneficial to establishing vegetation in such situations. When bulk density is low, mycorrhizae may be helpful in aggregating loose, unstable material.

Moisture retention characteristics

13. Moisture levels in dredged material can be determined by application of several water-related soil parameters. Those relevant to plant establishment and mycorrhization are water retention, available water capacity, and hydraulic conductivity.

14. Water retention. Water retention is the moisture-storing capacity of a soil. It is influenced by the arrangement of solid components of the soil or sediment, the quantity of fine particles, and the organic matter content. The clay fraction of dredged material has a high water-retention

capacity. Conversely, sand has very low water-retention capacity. Water-retention capacity of dredged material varies with texture, bulk density, and organic matter content. Gupta et al. (1978) developed a method for predicting water-retention characteristics of dredged material that takes these variables into account.

15. Available water capacity. Available water capacity is a term applied in agriculture to the amount of water a crop can remove from the soil before its yield is seriously affected by drought. Available water capacity is the difference between water-retention values (cubic centimetres of water per cubic centrimetre of substrate) at 0.33 bars (the moisture content at field capacity) and 15 bars (the permanent wilting point of many plants) (Gupta et al. 1978). Available water capacity of dredged material varies with site design and textural composition of the deposited material. In a study by Gupta et al. (1978), available water capacity ranged from 0.03 cm^3/cm^3 to 0.27 cm^3/cm^3 in dredged material samples from ten sites.

16. Hydraulic conductivity. Hydraulic conductivity is an expression of the ability of water to move through a material. It is determined by pore size and water-retention capacity. The clay fraction of dredged material exhibits low hydraulic conductivity; conversely, sand exhibits high hydraulic conductivity. Low hydraulic conductivity provides longer reaction times for dissolved contaminants and applied nutrients. In the Gupta et al. (1978) study, saturated hydraulic conductivities ranged from 0.3 cm/hr to 302.2 cm/hr at ten widely varied dredged material disposal sites. These values were high compared to agricultural field values which ranged from 2 to 5 cm/hr.

Extensibility

17. The coefficient of linear extensibility describes the swelling and shrinking potential of soils. Changes in soil volume can affect infiltration of nutrients and water. Excessive shrinking can cause cracks that increase water loss by evaporation. A coefficient less than 0.03 is considered most desirable for agricultural purposes. Dredged material has a relatively low coefficient (Gupta et al. 1978). In ten sites sampled, coefficients ranged from 0.000 to 0.074 ($\bar{X}$ = 0.024). Therefore, extensibility should not pose a problem to establishing vegetation in dredged material disposal sites, except in the few instances where extreme coefficients occur.

18. Moisture-retention characteristics of dredged material affect the types and success of establishing vegetation. Mycorrhizae have been shown to

extend the root systems of plants, thereby enhancing water-absorption efficiency and soil-moisture retention. Therefore, they may make a great contribution to revegetation of upland sites where moisture occurs at low levels.

Chemical Characteristics

pH and Eh

19. pH. The pH of dredged material from ten disposal sites located in the eastern and central United States varied from 2.9 to 7.9 (Gupta et al. 1978). Yu et al. (1978) found a range of 6.5 to 7.6 for four dredged material disposal sites. Significant increases in pH may occur during the dredging and disposal cycle, with average surface background water, influent, and effluent values of 6.6, 7.15, and 7.5, respectively (Hoeppel et al. 1978). However, several site-specific increases above 9 were reported. Such elevations in pH can be caused by high nutrient concentrations, low solids content, and long residence time of ponded water, which favors extensive photosynthesis by planktonic algae. Alkalinity showed an overall decrease during containment. Freshly dredged sediment pH values in eight disposal areas tested were found to be very close to neutral, which is typical for anaerobic sediments (Hoeppel et al. 1978).

20. Marine sediments frequently contain sulfides that oxidize to sulfates, consequently reducing pH to levels as low as 3.0 to 4.0 (Hunt et al. 1978). When available sulfur levels are high (530 to 1300 μg/g), application of lime is required to neutralize the acidity before revegetation efforts are undertaken (Gupta et al. 1978; Hunt et al. 1978; Yu et al. 1978). At one site, three times the normal rate (i.e., rate for agricultural soils) of application of lime was required to increase the pH from 3.1 to 6.4 (Gupta et al. 1978).

21. The limited available data indicate that pH in dredged material disposal sites varies, and is dependent on many factors [e.g., chemical characteristics of the dredged sediment (especially sulfide, nitrogen, and carbonate levels), solids content, biological activity, and containment time].

22. Eh. Electrochemical potential (Eh) is a measure of the availability of electrons in a system (Yu et al. 1978). Values of Eh give an indication of the overall oxidation-reduction intensities within a system. In one study, Eh values ranged from -232 to + 353 millivolts (mv) for dredged

material and -82 to + 368 mv for soils (Yu et al. 1978). This wide range in Eh, accompanied by a rather consistently neutral pH, is not uncommon in sediments and soils.

23. The Eh becomes extremely significant in predicting the availability of nutrients and toxins in dredged material. The oxidation states of hydrogen, carbon, nitrogen, oxygen, sulfur, and several metals are affected by Eh.

Cation exchange capacity

24. The exchange of one cation for another on soil colloids (cation exchange) is one of the most common and most important soil reactions. Cation exchange capacity (CEC) is the total exchangeable cations adsorbed by a soil, expressed in milliequivalents per 100 grams of dry soil (meq/100 g) (Millar et al. 1958). The CEC has a direct impact on availability of nutrients and other minerals present in a substrate.

25. Organic matter is responsible for most of the ion exchange in sediments due to the large surface area and the number of charged groups in organic matter (Hoeppel et al. 1978). Troth and Ott (1970) attributed 80 percent of CEC in bottom sediments to organic matter.

26. In river sediments, bay sediments, and freshwater impoundment sediments, CEC ranged from 7 to 100 meq/100 g, which was much higher than in soil (1 to 15 meq/100 g) (Troth and Ott 1970). This was probably due to the fine texture of deposited sediments (Brady 1974; Yu et al. 1978). Fine-textured soils tend to have higher CEC than coarse soils. In the study by Yu et al. (1978), a wide range of CEC was found in dredged material. Mean values reflected relative texture of samples, ranging from the lowest (11 meq/100 g) in sandy material to the highest (51 meq/100 g) in material having the highest clay content. The CEC values for all fine-textured dredged material samples were similar to those for productive agricultural soils (1.0 to 32.5 meq/100 g) (Gupta et al. 1978).

27. The CEC is also affected by pH. In most soils CEC increases with increases in pH (Brady 1974). No correlations between CEC and pH of dredged material were found in the literature.

Salinity

28. High salinity may be expected in dredged material taken from marine sources and from sediments high in salts from irrigation or fertilization practices. Saline dredged material can contain sufficient quantities of chloride to produce water quality problems in ground water into which leachates

penetrate (Yu et al. 1978). One measure of salt levels is electrical conductivity. The electrical conductivity of dredged material was almost always less than 2.0 mmhos/cm in tests by Gupta et al. (1978). They found conductivities of all the tested dredged material samples to be acceptable for agricultural purposes when compared to those recommended for crops in saline soils (less than 2.0 mmhos/cm), and that soluble salts did not limit plant growth in the study. However, in dredged material where salinity is excessive, an extended period may be required before leaching produces nontoxic levels, perhaps a year or longer (Hunt et al. 1978). Occasionally, treatment of a site with gypsum ($CaSO_4$) may be necessary before revegetation can commence. Unless salinity is exceptionally high, salt-tolerant plant species may naturally revegetate saline disposal areas (Hoeppel et al. 1978).

Phosphorus

29. The form in which phosphorus exists in soils varies with the pH of the soil solution. In acidic soils, H_2PO_4 ions predominate, while HPO_4 ions are most common in alkaline soils. A mixture of HPO_4 and H_2PO_4 ions is most desirable to prevent the formation of insoluble phosphorus compounds. Soil pH affects the solubility of phosphorus forms. At low pH (especially below 5), iron, aluminum, and manganese reactions increase, causing fixation of soluble phosphate into complex, insoluble phosphorus compounds of these elements. As the soil pH rises above 7, soluble phosphates complex with calcium forming insoluble calcium phosphate. Minimum phosphorus fixation occurs when the soil pH is in the range from 6.0 to 7.0 (Brady 1974). The presence of organic matter can reduce phosphorus fixation by binding much of the available iron and aluminum. The successful use of phosphorus fertilizers in combination with animal manure is evidence that organic matter increases availability of phosphorus (Brady 1974).

30. When soils are submerged and oxygen supply becomes depleted, phosphorus is liberated by hydrolysis of iron and aluminum compounds, and release from clay. Noncalcareous sediments resorb and retain much of this phosphorus. Therefore, water-soluble phosphorus is frequently low in acid clay sediments (Ponnamperuma 1972).

31. Some evidence suggests that phosphorus is insoluble during dredged material disposal activities and that the insoluble fraction is selectively retained within dikes constructed for marsh development (Lunz et al. 1978). The few studies for which data are available indicate that total phosphorus is

high in dredged material, but that it is frequently unavailable for uptake by plants.

32. Some of the conditions described for soils hold true in dredged material. Phosphate associates with iron and aluminum in acid materials, and with calcium in neutral and alkaline materials (Yu et al. 1978). In studies by Yu et al. (1978), total phosphorus content in dredged material samples ranged from an average of 1280 mg/kg to 1360 mg/kg. In another study, a high concentration of available phosphorus (39-120 kg/ha) was found in seven dredged material disposal sites, medium concentration (18 kg/ha) in one site, and low concentrations (4 and 11 kg/ha) in two sites (Gupta et al. 1978).

33. Phosphorus solubility and transport within dredged material is greatly dependent upon pH, just as in soils. The highest soluble phosphate concentration found in leachates of dredged material occurred in a sample having the highest pH, but all concentrations were low (Yu et al. 1978). Soluble phosphate ranged from 0 to 0.11 ppm (low level) in leachates of a confined land disposal area (Yu et al. 1978). When the concentration of phosphorus in leachates is low and total phosphorus in dredged material samples is high, phosphorus may occur in an insoluble or bound form, especially when pH is extremely high or extremely low. Therefore, phosphorus may be unavailable for plant uptake.

Nitrogen

34. Nitrogen exists in at least three forms in mineral soil: (a) organic nitrogen associated with soil humus, (b) ammonium nitrogen fixed by certain clay minerals, and (c) soluble inorganic ammonium and nitrate compounds. Most soil nitrogen is associated with organic matter and about half of that is in the form of amino compounds (Brady 1974). Nitrogen conditions in submerged soils differ from those in terrestrial soils primarily because of the reduced state of submerged sediments. The rate of organic matter degradation is considerably greater in oxidized soils than in reduced soils. Nitrogen requirements for anaerobic metabolism in reduced soils are so low that ammonium nitrogen release is greater than would be expected (Gambrell and Patrick 1978). Soil and sediment reduction resulting from submergence favors physical, chemical, and biological processes that remove available nitrogen. Therefore, nitrogen deficiency is common in sediments (Gambrell and Patrick 1978). Total Kjeldahl nitrogen (organic nitrogen) often decreases in sediments during disposal of dredged material (Lunz et al. 1978). Nitrogen

continued to decrease through the 2-year period following disposal. Yu et al. (1978) found an average onsite total Kjeldahl nitrogen in dredged material ranging from 269 mg/kg to 3170 mg/kg. The principal form of nitrogen in sediments was organic compounds, most of which occurred as protein fragments. Dredging results in a rapid release of ammonium to the solution phase (Hoeppel et al. 1978). Therefore, rapid conversion of ammonium to nitrate should be favored in land containment areas since oxidizing conditions generally prevail. However, data have failed to show a direct relationship between residence time and effluent nitrate concentration. High concentrations of ammonium nitrogen in disposal area effluents seem to be a major problem for the land containment of dredged material. Ammonium nitrogen concentrations in pore water of bottom sediments can average 130 mg/ℓ; however, additional ammonium may be released from solids as a result of the dredging operation (Hoeppel et al. 1978). In aqueous environments where the pH exceeds 8.5 (which may occur in some confined disposal areas), appreciable quantities of ammonium ions revert to free ammonia that not only escapes readily, but is very toxic.

35. Growth of saltmarsh cordgrass *(Spartina alterniflora)* in a Louisiana salt marsh was limited by nitrogen deficiency, in spite of high levels of total sediment nitrogen and comparatively high nitrogen mineralization rates. It has been suggested that loss of inorganic nitrogen is so rapid that plants are unable to use it (Patrick and DuLaune 1976). Analogous rapid loss of inorganic nitrogen may occur in marshes developed by disposal of dredged materials.

Potassium

36. The concentration of available potassium appears to be highly variable. The concentration of potassium was high in four tested dredged material samples (361-1577 kg/ha), medium (288 kg/ha) in one, and low (121-250 kg/ha) in five others (Gupta et al. 1978). Yu et al. (1978) found a higher concentration of potassium in dredged disposal sites than in offsite samples. Hoeppel et al. (1978) found no noticeable increases in soluble potassium during land containment of dredged material. Available potassium is readily lost by leaching and is reduced during the disposal process. Nevertheless, Gupta et al. (1978) found exchangeable potassium varied from 0.01 to 1.52 meq/100 g of dredged material, which is within normal ranges found in agricultural soils.

Organic matter

37. Dredged material contains a mixture of organic compounds, many of which are toxic and/or highly resistant to biochemical degradation. They include carbohydrates (e.g., cellulose and chitin), polyaromatic compounds (e.g., lignins and humic matter), and small soluble molecules (e.g., fatty acids, alcohols, and aldehydes) (Hoeppel et al. 1978). In one study, fine-textured dredged materials were higher in organic matter than were productive agricultural soils. The range for dredged material samples varied from 0.07 to 13.05 percent, compared with an average of 2.43 percent for productive agricultural soils (Gupta et al. 1978). In another study, total organic carbon in dredged material ranged from 0.27 to 3.8 percent. In that study high correlation between total organic carbon and alkalinity was also found. This was probably due to the correlation between alkalinity and carbonate, or bicarbonate ions (Yu et al. 1978).

Trace elements

38. Plant micronutrients. The eight commonly recognized plant micronutrients are iron, manganese, zinc, copper, boron, molybdenum, cobalt, and chloride (Brady 1974). Micronutrients are required by plants, but in extremely small amounts. As for other plant nutrients, availability of micronutrients is dependent upon substrate pH and oxidation-reduction intensity (Eh).

39. Low soil pH increases the solubility of iron, manganese, zinc, copper, boron, cobalt, and molybdenum. However, in strongly acid soils, molybdenum can become bound by other soil minerals (silicon, iron, and aluminum), limiting its availability (Brady 1974). Iron and maganese are more available in reduced flooded soils than in oxidized soils. In contrast, zinc and copper are less available in reduced flooded soils than in oxidized soils.

40. Iron. High concentrations of iron in dredged material occur mainly when acidic water contacts sediments or under reduced conditions in the absence of high sulfide levels (Hoeppel et al. 1978). Levels of soluble iron in dredged material are comparable to the surrounding environment, and are low when compared with the Environmental Protection Agency (EPA) drinking water standards (Yu et al. 1978). Of all the trace metals occurring in dredged material examined by Yu et al. (1978), only iron and manganese occurred in sufficient quantities to pose water quality problems.

41. Manganese. Manganese is the most soluble of the micronutrients (Yu et al. 1978). It has a greater tendency to be released into the aqueous phase of dredged material than iron, and remains in the soluble form for a longer period than iron (Hoeppel et al. 1978).

42. Zinc. Levels of soluble zinc were lower in onsite dredged material than in the surrounding soils (Yu et al. 1978). All sites averaged lower than the EPA drinking water standard for zinc (5 ppm). Insoluble zinc sulfide formation and possible greater zinc complexation with insoluble humic materials contribute to the decrease in zinc availability under reduced conditions (Gambrell and Patrick 1978). Removal of soluble zinc from dredged material has been attributed to biological uptake and to precipitation as carbonate complexes, while release of additional zinc is promoted by degradation of organic matter and solubilization of carbonate complexes (Hoeppel et al. 1978). More than 55 percent of the total zinc occurred in the organic-sulfide phase of influent solids in dredged material (Hoeppel et al. 1978).

43. Copper, lead, and cadmium. Stability of copper, lead, and cadmium complexes decreased with insoluble organics as reduced sediments were subjected to an oxidized environment (Gambrell et al. 1977). However, copper is relatively stable in most dredged material solids during the typically short retention time and mobility of copper should occur rarely in land containment areas (Hoeppel et al. 1978). Concentrations of copper (1 to 2616 $\mu g/\ell$) posed no threat to ground-water quality (Yu et al. 1978).

44. Chloride. Chloride ions move with water up and down within the soil profile. Chloride availability is seldom a problem in agricultural soils, but ions may be leached from soils in humid areas and concentrated to toxic levels in semiarid and arid areas (Brady 1974). The onsite chloride concentration ranged from an average of 167 mg/ℓ to 8333 mg/ℓ, which is typical for freshwater to brackish water systems (Yu et al. 1978). The concentration of available chloride is highly site-dependent.

Contaminants

45. Immobilization of contaminants that may be present in dredged material is frequently an objective of revegetation efforts. Retention of fine-grained solids in the containment area results in maximum retention of potentially toxic chemical constituents (Barnard and Hand 1978); therefore, vegetation establishing in these areas is especially subject to uptake of and/or inhibition by any contaminants that are present. The types of

contaminants and the levels at which they occur are site-specific. Some data available in the literature are indirect, examining the levels of hazardous leachates rather than levels of contaminants retained by dredged material. Most trace metals, oil and grease, and pesticides exhibit strong affinity for solid particles. The availability of contaminants to vegetation depends on the oxidation-reduction status of the dredged material as well as texture of the dredged material, and its organic matter content, and pH. Plant availability of heavy metals in dredged material is covered comprehensively in Simmers et al. (1981) and Folsom and Lee (1981a, 1981b).

PART III: MYCORRHIZAE

Definition

46. The word mycorrhiza (pl. mycorrhizae, or mycorrhizas), literally "fungus root," was coined in 1885 by A. B. Frank to describe the intimate association of plant roots with certain fungi (Maronek et al. 1981). These associations are usually mutualistic (i.e., beneficial to both the plant and the fungus) and are by definition nonpathogenic (Smith 1980). Almost without exception, mycorrhizae enhance plant growth. They tend to be rather constantly present and specific to plant species. Very few plants have been found to lack mycorrhizae.

47. Mycorrhizae are associated with autotrophic or heterotrophic plants. They may be obligate symbionts, active saprophytes, or even parasitic. Mycorrhizal fungi utilize the host plant as a carbohydrate source since they are incapable of carbohydrate synthesis. They contribute to the mineral nutrition of the host plant by extending the absorptive area of the root system, thereby increasing absorption efficiency.

Types of Mycorrhizae

48. Mycorrhizae are divided into two broad classes, ectomycorrhizae and endomycorrhizae, based on the method by which the fungus is attached to roots of the host plant. This simple structural basis for classification does not reflect physiological relationships, which have only recently begun to be investigated and which many feel will provide more accurate and concise classification categories (Smith 1980). Overlapping exists between the two classes, and mycorrhizae exhibiting characteristics of both classes are described as ectendomycorrhizae.

Ectomycorrhizae

49. Ectomycorrhizal fungi do not penetrate host root tissue (Figure 1). Instead, they colonize the intercellular spaces of the cortical cells forming a network of hyphae called the "Hartig net." Root colonization is usually visible as a fuzzy mycelium covering the small feeder roots (Beattie 1976). Hyphae can radiate from the root surface several metres into the soil. The

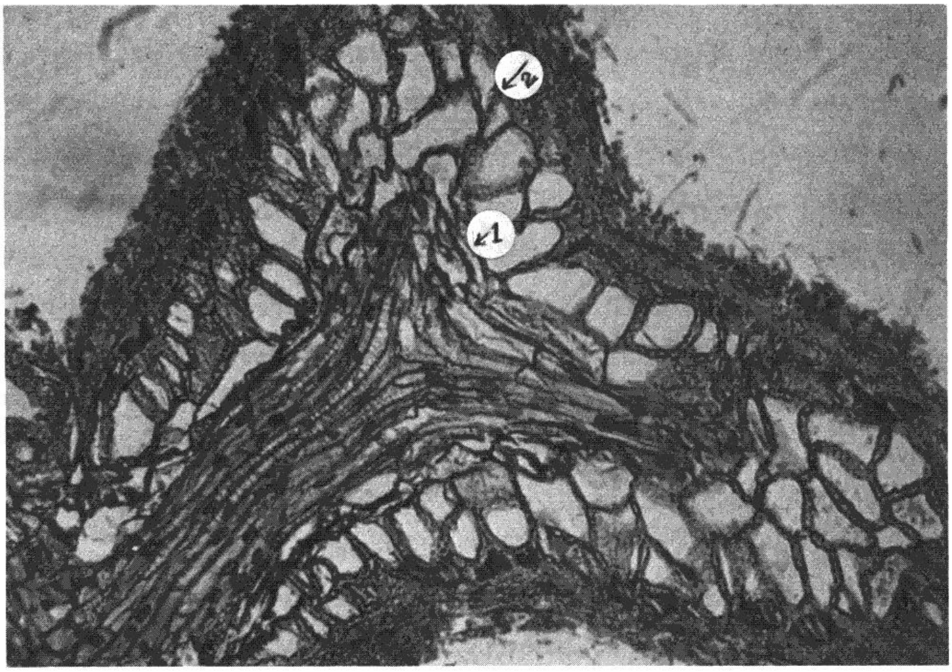

Figure 1. Longitudinal section of *Pisolithus tinctorius* ectomycorrhiza on loblolly pine (*Pinus taeda*). The first arrow (1) indicates the root cortex; the second arrow (2), the "Hartig net" formed by the ectomycorrhizae. (Dr. Donald H. Marx, Director and Chief Plant Pathologist, Institute for Mycorrhizal Research and Development, US Department of Agriculture, Forest Service, Athens, Ga., provided all photographs appearing in this report)

hyphae greatly increase the absorptive ability of the roots. In return, the fungus absorbs reduced carbon compounds exuded from the roots (Maronek et al. 1981).

50. Ectomycorrhizae are known to occur in about 2000 plant species and are most common in the plant families Pinaceae, Salicaceae, Betulaceae, Fagaceae, Tiliaceae, Rosaceae, Leguminosae, Ericaceae, and Juglandaceae. Ectomycorrhizal fungi most frequently encountered belong to the class Basidiomycetes and include the following families: Amanitaceae, Boletaceae, Cortinariaceae, Russiclaceae, Tricholamataceae, Rhizopoganaceae, and Sclerodermataceae. Certain orders of Ascomycetes (Eurotiales, Tuberales, Pezizales, and Helotiales) also form ectomycorrhizae (Maronek et al. 1981; Pirozynski 1981).

Endomycorrhizae

51. Endomycorrhizal fungi penetrate the host root epidermis or root

hairs and enter the cortical cells of the root. The mycelium is usually not visible, but a network of fine, hairlike hyphae extend outward several centimetres from the root (Maronek et al. 1981). Short-lived vesicles and arbuscules (specialized fungal structures) are frequently produced within the root cortex (Figure 2). Discovery of these structures has given rise to a subclass of endomycorrhizae known as vesicular-arbuscular mycorrhizae (VAM) (Maronek et al. 1981). The spores of VAM are formed outside of the root (Figure 3).

52. Endomycorrhizae are the most widely distributed class of mycorrhizae. Their spores occur in nearly all natural soils (Marx and Beattie 1977). Most endomycorrhizal fungi belong to the class Phycomycetes and include the genera *Glomus*, *Sclerocystis*, *Endogone*, *Gigaspora*, and *Acaulospora*. All of these form VAM. Certain members of the class Basidiomycetes also form endomycorrhizae, primarily in association with members of the plant families Orchidaceae, Gentianaceae, and Ericaceae.

Factors Affecting Establishment and Growth of Mycorrhizae

53. Many factors influence the establishment and growth of mycorrhizae. Their intimate association with the soil makes them sensitive to all variations in soil conditions (e.g., nutrient level, pH, temperature, moisture content, aeration, and salinity). Environmental conditions such as light and atmospheric pollutants also influence mycorrhizae. Other conditions that affect plant vigor also have potential effects upon mycorrhizae. Ecological factors (e.g., residual inoculum in the soil from a previous plant community and interactions with adjacent fungal communities or other soil microorganisms) influence mycorrhizal development. Intrinsic factors (e.g., source and age of the fungal inoculum and stimulation by host excretions) determine the type and extent of fungal colonization of the host root system. Each of these major factors are discussed below.

Soil conditions

54. Soil conditions exerting the greatest influence on mycorrhizae include nutrient levels, pH, temperature, and moisture. Effects of the physical and chemical characteristics of soil (e.g., texture, bulk density, extensibility, Eh, cation exchange capacity, and salinity) have been mentioned in the literature only incidentally to reclamation efforts (Part IV). No

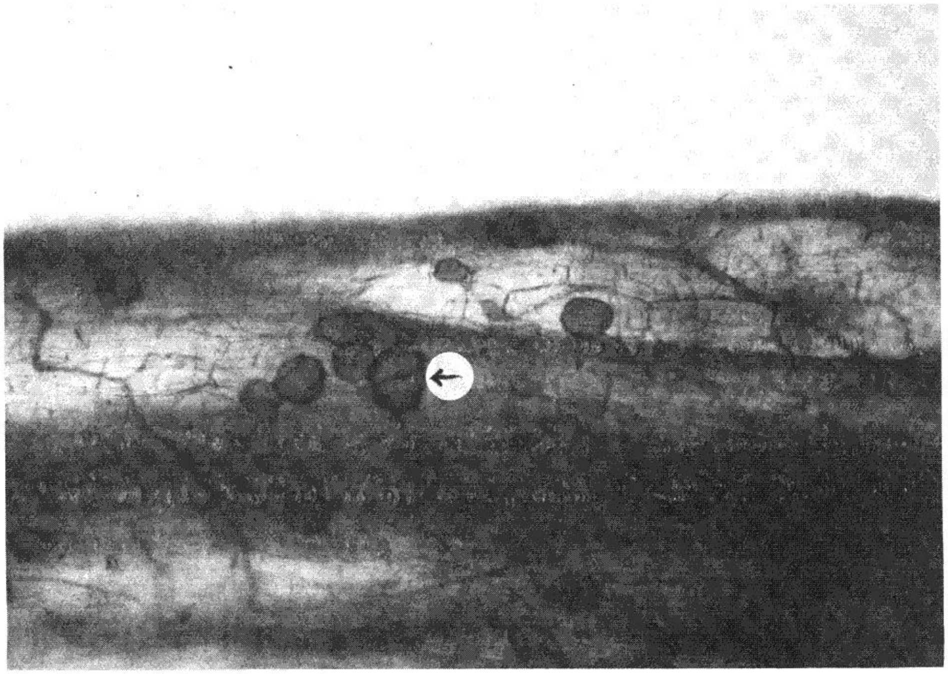

Figure 2. VAM of sweetgum (*Liquidambar styraciflua*) showing internal vesicules and small arbuscules (arrow)

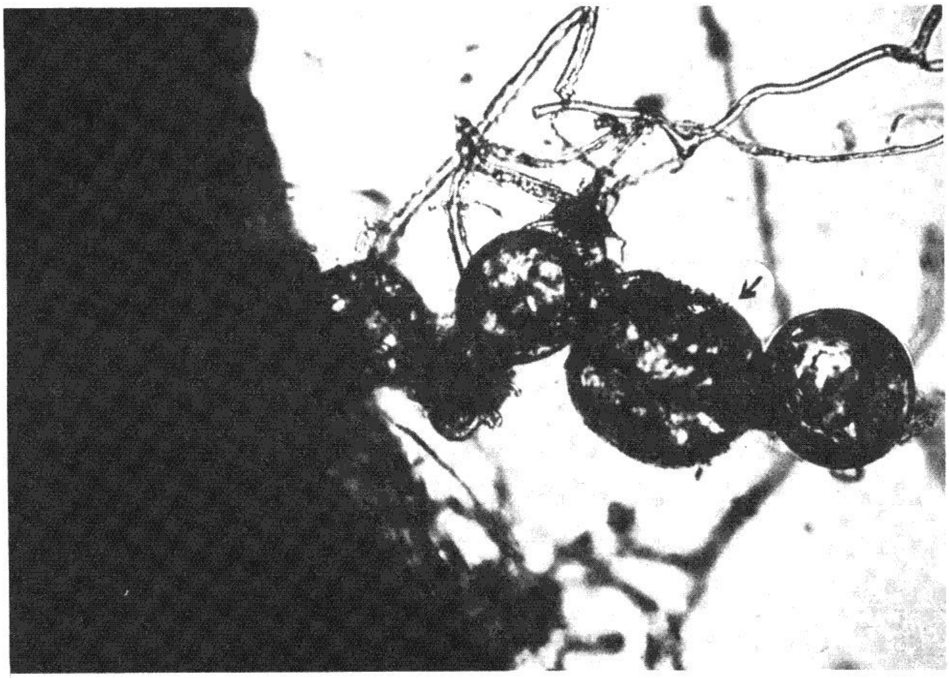

Figure 3. Spores of VAM (arrow) fungi outside of sweetgum VAM

reference was found describing the effects of iron, molybdenum, cobalt, or chloride on mycorrhizae, either in levels considered to be excessive or deficient for plant growth.

55. Phosphorus. Mycorrhizae flourish in low phosphorus soils and are inhibited by high phosphorus soils. The literature substantiates this fact for a wide range of plant species. Examples of species for which this is true are listed below:

Scientific Name	Common Name	Source
Allium cepa	Onion	Nelsen et al. (1981); Ojala (1982)
Citrus aurantium	Brazilian sour orange	Ratnayake et al. (1978)
Elymus sp.	Ryegrass	Jasper et al. (1979); Powell et al. (1980)
Glycine max	Soybean	Bethlenfalvay et al. (1982a)
Hordeum vulgare	Barley	Jensen (1982); Jensen and Jakobsen (1980)
Medicago sativa	Alfalfa	Barea et al. (1980)
Pinus rigida	Pitch pine	Lee (1981)
P. strobus	Eastern white pine	Piché and Fortin (1982)
Quercus rubra	Red oak	Ruehle (1980a)
Q. velutina	Black oak	Dixon et al. (1981c)
Sorghum vulgare	Sudangrass	Ratnayake et al. (1978)
Trifolium spp.	Clover	Powell (1980a, 1980c); Powell et al. (1980)
Triticum spp.	Wheat	Jensen and Jakobsen (1980)
Vigna unguiculata	Cowpea	Islam et al. (1980)

At least two reasons have been proposed to explain mycorrhizal dependence on low phosphorus levels. Net leakage of soluble amino acids and reducing sugars from plant roots are lower in high phosphorus soils (Dixon et al. 1981c; Graham et al. 1982; Jasper et al. 1979; Ratnayake et al. 1978). Phosphorus within the root tissue apparently induces a decrease in phospholipid levels, which decreases membrane permeability to nutrients that could have been exuded. These essential nutrients are then unavailable to the fungi for use in establishment and growth, resulting in inhibition of mycorrhizal development. It has also been suggested that high phosphorus concentrations produce host resistance to mycorrhizal fungal infection by some mechanism other than nutrient restriction (Jasper et al. 1979); however, this hypothesis has not been confirmed.

56. Many factors have been found to influence phosphorus inhibition. Reduced light intensity increased phosphorus inhibition of VAM in sudangrass when phosphorus was added to the soil (Graham et al. 1982). In low phosphorus soil (0.5 mg P/kg), decreased light intensity did not affect VAM formation. The reason suggested for lack of effect is that root phosphorus content did not change and root exudation was not reduced. Increased soil temperature counteracts phosphorus inhibition by directly increasing root exudation of nutrients, thereby stimulating mycorrhizal fungi (Graham et al. 1982).

57. Phosphate fertilizers generally exert the same effect on mycorrhizal development as naturally high soil phosphorus levels (Barea et al. 1980; Hayman 1981; Jasper et al. 1979; Jensen and Jakobsen 1980; Lee 1981; Nelsen et al. 1981; Piche and Fortin 1982; Powell 1980a, 1980c; Powell et al. 1980; Ratnayake et al. 1978; Ruehle 1980). Superphosphate depresses infectivity of mycorrhizal fungal inoculum not only by decreasing sporulation, but also by stimulating production of fungal propagules that are less aggressive in colonizing roots (Powell 1980a). As soil phosphate levels increase, fewer external hyphae are produced, and host dependency on mycorrhizae for phosphorus decreases.

58. Hayman (1981) suggested that the primary effect of mycorrhizae is improved phosphorus uptake, and that plants with fine, fibrous root systems only need mycorrhizae in phosphorus-deficient soils, while coarse-rooted plants may need mycorrhizae even when supplied with moderate levels of phosphate fertilizer. However, Powell (1980a) found that mycorrhizae remain important in phosphorus nutrition of white clover even when moderate to heavy levels of phosphate are applied. Pines normally infected by mycorrhizae can grow without them when phosphorus is supplied (Marais and Kotzé 1978b). Phosphorus metabolism of mycorrhizal native grasses and grains has been studied extensively (Jasper et al. 1979; Powell 1980a, 1980c; Powell et al. 1980; Rabatin 1979). In general, mycorrhizae have been shown to improve phosphorus uptake in these fibrous-rooted plants.

59. Mycorrhizae may be effective in high phosphorus soils where high levels of calcium and clay cause fixing of phosphorus. In such soils, total phosphorus is high, but available phosphorus is low. Plants can also respond to mycorrhizal inoculation even after appreciable amounts of fertilizer have been added to such soils (Hayman 1981). Therefore, mycorrhizae are capable of making bound phosphorus available to plants.

60. High soil phosphorus levels do not always suppress mycorrhizae. Much depends on other chemical aspects of the soil and on the form of phosphorus present. The addition of sparingly soluble rock phosphate to phosphorus retaining soils does not impede mycorrhizae formation even when levels are high enough to stimulate plant growth (Powell 1980b).

61. One means of mitigating the potential inhibition of phosphorus fertilizers to mycorrhizae has been foliar application of phosphorus. Black oak seedlings receiving foliar fertilizer developed 36 percent more ectomycorrhizal roots than seedlings receiving fertilizer in growth medium (Dixon 1981c).

62. In summary, mycorrhizae may (a) increase phosphorus absorption by the host plants in phosphorus-deficient soils and in soils having bound forms of phosphorus and (b) be inhibited by soils with abundant available phosphorus and by phosphate fertilizers. However, many factors other than soil phosphorus concentration affect the interaction between mycorrhizae, soil phosphorus, and the host plant.

63. Nitrogen. The literature generally supports a correlation between increased levels of soil nitrogen and decreased incidence of mycorrhizal infection (Chambers et al. 1980a, 1980b; Hayman 1981; Jensen and Jakobsen 1980; Lee 1981; Marais and Kotzé 1978b; Ruehle 1980a). An explanation for this is that in high soil nitrogen conditions the host plant diverts its energies toward protein synthesis rather than for carbohydrate synthesis. Mycorrhizal fungi have only limited ability to compete with the plant for the reduced carbohydrate supply (Maronek et al. 1981).

64. Soil nitrogen may be available to mycorrhizae in the form of ammonium ions, nitrate ions, and/or organic nitrogen compounds or ions. These various forms have different mobilities in the soil and different assimilation pathways in fungal and plant tissues (Smith 1980). The form of nitrogen affects other aspects of soil chemistry that may be important in its uptake

and to the vigor of the mycorrhizal fungus and its host. For example, ammonium and nitrate ions contribute to total salt concentration in the soil along with such ions as phosphate, potassium, sulfate, and chloride. The few studies that have been conducted on the effects of high soil salt concentrations (usually phosphate salts) suggest that they are inhibitory to mycorrhizae (Chambers et al. 1980b). Soil pH is also affected by the form of nitrogen present in the soil. Ammonium assimilated into amino acids results in a decrease in soil pH (Smith 1980). On the other hand, nitrates assimilated by mycorrhizal fungi are reduced, producing an excess of hydroxyl ions that can be excreted into the soil, causing an increase in soil pH (Smith 1980). Distribution of fungal species is frequently dictated by soil pH.

65. Several studies have been conducted to compare effects of various forms of nitrogen on mycorrhizae (Beckjord et al. 1980; Brown et al. 1981; Chambers et al. 1980a, 1980b; Peeler and Mullins 1982; Smith 1980). Greater reductions in mycorrhizal infection of clover occurred with ammonium ions than with nitrate ions (Chambers et al. 1980a, 1980b). However, greater root and leaf nitrogen content occurred in mycorrhizal sweetgum seedlings that were given ammonium sulfate than in those receiving either ammonium nitrate or potassium nitrate (Brown et al. 1981). This suggested that mycorrhizal sweetgum seedlings preferentially take up ammonium nitrogen over nitrate nitrogen. The nitrogen requirement of *Pisolithus tinctorius* in laboratory cultures can be satisfied with nitrate alone (Peeler and Mullins 1982).

66. The age of red oak seedlings at the time of application of nitrogen fertilizer greatly affected mycorrhizal response (Beckjord et al. 1980). Sodium nitrate enhanced mycorrhization when applied to 40-day-old seedlings more than application of either sodium nitrate or ammonium chloride enhanced 15-day-old seedlings.

67. Accompanying minerals also influence nitrogen effectiveness of mycorrhization (Dixon et al. 1979). Nitrogen applied to foliage of shortleaf pine seedlings (*Pinus echinata*) increased mycorrhization. Nitrogen and zinc in combination was a more effective promoter of mycorrhization than nitrogen and magnesium when applied to foliage. Nitrogen and zinc applied to foliage was more effective than either nitrogen and zinc or nitrogen and magnesium applied to rooting medium.

68. Urea, a simple organic form of nitrogen, inhibited mycorrhizal formation when applied to Douglas fir seedlings (*Pseudotsuga menziesii*) in concentrations greater than 100 ppm available nitrogen (Sinclair 1974). This was the only study found on effects of organic nitrogen.

69. Variability in effects of nitrogen on mycorrhization is an indication that complex factors influence its availability and uptake. The form in which nitrogen occurs in the soil, other aspects of soil chemistry, and characteristics of specific plant/fungus associations may all contribute to nitrogen effects on mycorrhization.

70. Inconclusive evidence has been presented that mycorrhizae fix atmospheric nitrogen. Certain ectomycorrhizal and endomycorrhizal fungi have been found to exhibit nitrate reductase activity (Trappe 1977; Ho and Trappe 1975). Mycorrhizae have been found on plants capable of fixing nitrogen, and mycorrhizae are known to stimulate nodulation of these plants (Maronek et al. 1981). However, actual nitrogen fixation by mycorrhizal fungi has not been conclusively demonstrated.

71. Potassium. Even though potassium is a major component of most fertilizers, no studies were found dealing with its individual effects on mycorrhization apart from phosphorus and nitrogen. Mycorrhizae increased plant uptake of potassium in potassium-deficient soils (Powell 1975), but no data were found concerning the effects of high potassium concentrations on mycorrhizae. Inhibition by high levels of applied NPK fertilizers have been documented (Csinos 1981), but much of this effect may be attributable to phosphorus.

72. Micronutrients. The relationships of several micronutrients to mycorrhizae have been studied. As concentrations of manganese (0.014-1.4 mg/ℓ), copper (0.1-1.0 mg/ℓ), and zinc (0.7-7.0 mg/ℓ) ions increased in cultures of *Glomus caledonius* spores, germination decreased (Hepper 1979). Excess zinc was found to be toxic to mycorrhizal fungi (Hepper and Smith 1976; McIlveen 1977 cited by Lambert et al. 1980a), and copper, although tolerated at low levels by endomycorrhizae of certain citrus species, prevented establishment of ectomycorrhizae (Harris and Jurgensen 1977; Lambert et al. 1980a). Highest uptake of cadmium, zinc, and phosphorus by mycelia of *Amanita muscaria* and *Suillus variegatus* (ectomycorrhizal fungi) occurred during the most intensive growth of mycelia. These elements can be absorbed rapidly by the fungi without the influence of mycorrhization (Stegnar et al. 1978).

73. Fertilization of soil with 1.1 ppm boron increased shoot dry weight of mycorrhizal clover by an average of 16 percent, but did not affect nonmycorrhizal clover weight. Inadequate levels of boron reduced shoot dry weight of mycorrhizal plants by 71 percent versus a reduction of 35 percent for nonmycorrhizal plants. Growth of both mycorrhizal and nonmycorrhizal plants decreased when excess boron was present, but colonization by mycorrhizae was unaffected. Uptake of phosphorus and copper was improved by boron application (Lambert et al. 1980b).

74. Organic matter. Several studies have been conducted that illustrate the transfer of carbon compounds, particularly sugars, from host plants to mycorrhizal fungi (Bevege et al. 1975; Lewis 1975; Purves and Hadley 1975; Stribley and Read 1975). However, only limited investigations were found on the effect of soil organic levels on mycorrhizae. An organic layer in the soil inhibited both growth and mycorrhization of white fir (*Abies concolor*) (Alvarez, Rowney, and Cobb 1979). Dry weight, total root length, total number of mycorrhizal tips, and the number of mycorrhizal tips per centimetre of roots were higher in seedlings grown in mineral soils than in those grown in mineral soils with an organic layer. A negative correlation was found between percent of mycorrhizal tips or number of mycorrhizal tips per centimetre of roots in a hybrid pine (*Pinus rigida* x *taeda*) with soil organic matter (Lee 1981). Apparently, addition of organic matter inhibits mycorrhizae in soils of poor to moderate fertility.

75. pH. The literature presents conflicting reports on whether or not pH affects mycorrhizal development. A positive correlation was found between percent mycorrhizal tips or numbers of mycorrhizal tips per centimetre of root in hybrid pine with soil pH (Lee 1981). A very slight correlation occurred between infection percentage, clay content, and pH on 2-year-old barley crops in commercial fields (Black and Tinker 1979). However, much more evidence has been cited that pH has no effect on mycorrhization. A 5-year study of barley, oats (*Avena sativa*), wheat (*Triticum* sp.), and rye led to the conclusion that neither soil type nor pH had a determinable effect on mycorrhizal infection (Strzemski 1974). Nonmycorrhizal roots of these cereals were generally deformed, but this was also unrelated to soil type or pH. Neither nitrogen application nor pH change caused by lime dressing had any effect on mycorrhizal infection in Pennine grasslands (Sparling and Tinker 1974). Jelecote pine (*Pinus patula*) developed mycorrhizae equally well over pH ranging from

4.8 to 7.1, indicating a low degree of pH specificity (Marais and Kotze 1978a). Mycorrhizal infection of citrus roots did not change significantly with pH (Ojala 1982). The wide tolerance of pH ranges described above can be attributed to several factors (e.g. differences in host characteristics and differences in soil nutrient levels). Mycorrhizal host plants apparently exert a strong influence on the absorption efficiency of VAM at different pH values in association with the same fungus. Mycorrhizal infection (*Glomus macrocarpus*) changed the influence of pH and absorption of phosphorus compounds differently in marigold (*Tagetes minuta*) and *Guizotia abyssinica* (Graw 1979). Mycorrhizae depressed phosphorus absorption in *G. abyssinica* at pH 4.3 in the presence of fertilizer compounds, whereas marigold absorbed phosphorus well at pH 4.3. Increased pH (6.6) improved phosphorus uptake and growth of mycorrhizal *G. abyssinica*, but either did not change, or decreased, absorption by mycorrhizal marigold (Graw 1979).

76. The specific host-fungus association itself seems to be dependent on pH. Responses of soybean cultivars to two mycorrhizal fungi (*Gigaspora gigantea* and *Glomus mosseae*) were compared in limed (pH 6.2) and unlimed (pH 5.1) soils (Skipper and Smith 1979). Greater responses were obtained with *G. mosseae* in limed soil and with *G. gigantea* in unlimed soil.

77. Several investigators have demonstrated the complexity of soil nutrient interactions with pH (Graw 1979; Lambert et al. 1980a; Marais and Kotze 1978a; Ojala 1982). Changes in pH influence the solubility of various phosphorus compounds and alter the absorption of phosphorus by soil components (fertilization effectiveness) differently (Graw 1979; Ojala 1982). Zinc, copper, iron, manganese, and aluminum vary in their availability with pH, and their concentrations may be of equal or greater importance than hydrogen ion concentration per se in the effect of soil acidity on mycorrhization (Lambert et al. 1980a).

78. Soil pH perhaps exerts selective pressure on mycorrhizal formation and specificity. Spore numbers are more closely related to pH than to other soil factors (e.g., organic matter, potassium, or phosphorus) (Kruckelmann 1974). Different species of endomycorrhizal fungi germinate at different pH levels and it has been suggested that pH thereby contributes to fungal distribution and host range (Green et al. 1976). Distribution of "honey-colored sessile" and "yellow vacuolate" spore types in western Australia has been related to soil pH (Abbott and Robson 1977; Hayman 1982).

79. Temperature. Most investigators agree that high soil temperatures promote mycorrhizae formation (Daniels and Trappe 1980; Graham et al. 1982; Marais and Kotzé 1978c; Pugh et al. 1981; Smith and Bowen 1979; Warnke 1982). Increased root temperature was positively associated with increased numbers of "entry-points" during the preinfection phase in mycorrhizal *Medicago truncatula* and subterranean clover (*Trifolium subterraneum*) grown in soils at 12°, 16°, 20°, and 25°C. Infection of roots was so intense at 20°C and 25°C at 10 and 12 days, respectively, that it was no longer possible to accurately count entry-points (Smith and Bowen 1979). Mycorrhization of cotton (*Gossypium hirsutum*) by *Gigaspora margarita* was stimulated at 30°C and 24°C and was slight or absent at 19°C or 14°C. Root infection was also abundant (65 percent) at the two higher temperatures, less than 5 percent at 19°C, and undetected at 14°C (Pugh et al. 1981). Jelecote pine mycorrhization was stimulated by high temperatures, but this did not result in increased growth (Marais and Kotzé 1978c). Three explanations for this result were suggested:

a. High temperatures may stimulate root exudation of substances which stimulate the mycorrhizal fungi, and the composition of these substances may also undergo changes at higher temperatures (35°C) to the advantage of the fungi.

b. Short root production may be stimulated by high temperatures, which in turn increases the number of infection sites, resulting in a higher incidence of mycorrhizal infection.

c. Optimum temperature for growth of mycorrhizal fungi of Jelecote pine may be relatively high.

80. Most mycorrhizal fungi have an optimum temperature for establishment of the symbiotic relationship and survival of the mycorrhizal condition. However, there may be considerable variation in the temperature tolerance of fungal species (Maronek et al. 1981). The optimum temperature for germination of *Glomus epigaeus* spores is between 18°C and 25°C (Daniels and Trappe 1980). Optimum germination may be closely correlated with optimum growth conditions of the host. There is some indication that optimum temperatures may be an adaptation to climatic conditions. Higher optimum temperature was found for *Gigaspora* spp. from Florida than for *Gigaspora* spp. from eastern Washington (Daniels and Trappe 1980).

81. Phosphorus inhibition of VAM can be overcome by increased soil temperature (Graham et al. 1982). Reduced inhibition in plants treated with 15 mg/kg phosphorus was associated with significant increases in root membrane permeability and exudation without a corresponding change in root phosphorus

concentration. Higher soil temperature may increase VAM formation through a direct effect of temperature on the fungus, or an indirect effect through an increase in leakage of root metabolites necessary for fungal activity, or both.

82. Moisture. Most mycorrhizal fungal spores are capable of germinating under conditions of high moisture. Maximum germination of *Glomus epigaeus* occurred in petri dish cultures at moisture levels above field capacity (Daniels and Trappe 1980). However, laboratory cultures are not subject to the great reduction in aeration that accompanies soil saturation with water. Waterlogging of soils has been shown consistently to suppress mycorrhizal function, probably due to insufficient oxygen for the fungi (Hayman 1981). Oxygen concentration in the soil atmosphere greatly influenced the growth and mineral uptake of thoroughwort (*Eupatorium adoratum*) inoculated with *Glomus macrocarpus* (Saif 1981). Similar effects can be expected with other mycorrhizal fungi since all are aerobic. Mycorrhizae often become established during dry periods on plants that grow under nearly continuous inundation (Warnke 1982). For example, trees commonly associated with periodic and continual inundation became mycorrhizal when drier conditions prevailed (Keeley 1980; Warnke 1982), and roots of rice (*Oryza sativa*) were devoid of VAM infection in flooded soils, but became infected under drier conditions (Gerdemann 1974). Spore production is also reduced under waterlogged conditions (Redhead 1971 cited by Warnke 1982). Studies of sorghum (Sieverding 1979) and other grasses (Rabatin 1979) showed that soil moisture affected the degree of infection. Greater development of mycorrhizae occurred under water-deficient conditions. When soil moisture content is seasonal (e.g., high in spring) mycorrhizal development occurs only after moisture levels have declined (Rabatin 1979).

Environmental factors

83. Light. There is conflicting evidence in the literature as to whether mycorrhizae develop better at high or at low light intensities. *Cenococcum graniforma* associations with beech (*Fagus* sp.) (Harley and Waid 1955) and birch (*Betula* sp.) (Mikola 1948 cited by Maronek et al. 1981), and *Gigaspora calospora* associated with onion (Furlan and Fortin 1977) were enhanced by low levels of light. However, *Pisolithus tinctorius* with eastern white pine (Piché and Fortin 1982) and *Endogone* sp. on onion (Hayman 1974) were inhibited at low light intensities. Higher light intensities increase

photosynthetic activity and subsequent carbohydrate translocation to the roots where mycorrhization can be stimulated (Maronek et al. 1981).

84. Effects of light on mycorrhization are probably complex. Light could exert an influence on many factors that affect mycorrhizae, including specific plant/fungus interactions. Light intensity and soil temperature affect the relations between phosphorus nutrition, root exudation, and VAM formation in sudangrass (Graham et al. 1982). Phosphorus-induced inhibition of VAM formation was increased at low light intensities because phosphorus content of roots corresponded with decreases in root membrane permeability and exudation. All of these factors are related to the photosynthetic system of the plant. Thus, the effects of light are probably indirect, exerting an influence via the mechanisms of photosynthesis and nutrient translocation.

85. Inhibitors. Many substances exert inhibitory or lethal effects on mycorrhizae. Pesticides, atmospheric pollutants, and specific metabolic inhibitors can affect mycorrhizae. VAM are affected by an array of substances, which include fungicides, general biocides, nematocides, and insecticides (Ocampo and Hayman 1980). Usually the effect is deleterious, causing decreased mycorrhization and reduced numbers of fungal spores. These negative effects may be greatest in less fertile soils where plants are more dependent on mycorrhizae. Substances toxic to mycorrhizae are not necessarily toxic to plants. On the other hand, mycorrhizae are often capable of overcoming inhibition by substances toxic to host plants.

86. Fungicides have been shown to decrease mycorrhizal development and sporulation (Jalali and Domsch 1975; Rhodes and Larsin 1979 cited by Warnke 1982). However, when mycorrhizae are abundant and thoroughly embedded in root material, much higher doses of fungistatic fumigants are necessary to kill them than to kill the common targets of fumigation (e.g., plant pathogenic fungi). Therefore, soil fumigants do not completely eliminate mycorrhizal fungi in treated fields.

87. Atmospheric pollutants may exert an influence over mycorrhizal fungi. Mycorrhizal fungi of a forest community were changed over a long period by fallout of industrial ash and dust (Sabotka 1974 cited by Maronek et al. 1981). Effects of atmospheric pollutants on mycorrhizae must surely be related to effects on the host plant and on the chemical characteristics of the soil.

88. Few studies have addressed the response of ungerminated spores to

inhibitors of protein and nucleic acid synthesis. Responses of *Glomus caledonius* spores to cycloheximide, actinomycin D, proflavin hemisulphate, 5-fluorouracil and ethidium bromide resemble those of saprophytic fungi more than those of obligate fungi (Hepper 1979). Cycloheximide, a specific inhibitor of protein synthesis, prevents germination of *G. caledonius* spores, as is the general case with obligate pathogens and with many saprophytes. Actinomycin D, thought to be an inhibitor of messenger RNA synthesis, prevented branching of *G. caledonius* germ tubes. Proflavine hemisulphate inhibited germination by reducing RNA synthesis. Germination and growth of *G. caledonius* were sensitive to 5-fluorouracil, which stimulates synthesis of ribosomal and soluble RNA. Ethidium bromide, a specific inhibitor of mitochondrial DNA synthesis, prevented or delayed germination at 5 and 3 μg/ml, respectively. Pregerminated spores were less sensitive (Hepper 1979).

Ecological factors

89. Residual inoculum. Mycorrhizal establishment is subject to the selective pressures of the soil environment. However, experimental evidence has shown that field plots inoculated with *G. caledonius* retain high levels of the fungus for as long as 21 months even though the soil already contained other mycorrhizal fungi (Mosse et al. 1982). The residual growth may be due to the continuous presence of a host plant over winter, which was the case in the cited study. A long delay was found before appreciable percentage infection of roots developed with all rotations of barley and kale (*Brassica oleracea*) with fallow fields over 2 years. Once mycorrhization commenced, it increased rapidly until a constant level was achieved, but this level was reached relatively late in the growing season. Presence of the host plant seems to be a requirement for maintenance of residues from one growing season to another. Such late infection appearance is unlikely to be beneficial to crops that are rotated (Black and Tinker 1979).

90. Host stimulation. Mycelial growth is subject to or regulated by many host plant hormones. Most of these interactions are not thoroughly understood, but researchers have proved that certain unidentified substances from the host plant are capable of controlling mycorrhization (Maronek et al. 1981). Cytokinins from pine seedlings stimulate mycelial growth of *Boletus edulis* var. *piniculus* (Gogala 1970 cited by Maronek et al. 1981). In addition, indolacetic acid, diphosphopyridine nucleotide, colchicine, kinetin, and various vitamins stimulate mycorrhizal fungi (Maronek et al. 1981).

PART IV: BENEFICIAL USES

Habitat Development

91. Revegetation of dredged material for the reclamation or establishment of habitat is both a means of stabilizing dredged material (thereby preventing its return to the waterway and reducing future maintenance dredging), and a means of conserving environmentally and economically productive ecosystems.

Aquatic habitat development

92. Marine. Typical submersed habitats extend from near sea level down to several metres. Examples are tidal flats, oyster beds, seagrass meadows, and clam flats (Smith 1978). Revegetation efforts have focused on establishment of seagrass beds.

93. Dredging and disposal activities in shallow coastal areas often destroy seagrass beds, eliminating shelter areas and food resources for many associated organisms. The extensive loss of the beds can impact commercial fishing, including shellfishing and shrimping. The goal of developing aquatic habitat in dredged and disposal areas is recovery of these highly productive ecosystems (Phillips et al. 1978). Seagrass beds do not recover rapidly following physical disturbance. For example, turtlegrass beds *(Thalassia testudinum)* damaged by motorboat propellers require 2 to 5 years to recover sufficiently to blend with surrounding undisturbed areas (Zieman 1976).

94. The greatest difficulty in revegetation of dredged areas and dredged disposal sites with seagrasses is stabilization of the plants in tidal currents. Once this is accomplished, plants are likely to survive, unless other growth conditions are inadequate. Nutrient limitations are not usually a problem in seagrass establishment, but favorable responses have been demonstrated by the addition of fertilizers (Orth 1977; Orth and Moore 1982b). Sediment texture appears to have a very important influence on nutrient levels. Limited available data indicate that fine-textured sediments are higher in nutrients than coarse-textured sediments. This is probably due to the negligible adsorption of exchangeable nutrients on coarse-textured sediments (Orth 1977). There is also some indication that pH and Eh, which greatly affect nutrient availability, are lower in coarse-textured sediments (Zieman 1976). Although the reducing environment in marine sediments forms a

sink for many heavy metals, there is no evidence that these metals affect the seagrasses (Phillips 1980).

95. None of the seagrasses used in revegetation of dredged material have been investigated to determine their mycorrhizal status. The study of marine fungi in general is very new and extremely limited. The high salt tolerance required, the generally reduced sediment environment, and the fibrous nature of seagrass root systems decrease the likelihood that mycorrhizae are present, and, if present, that they play any significant role in seagrass establishment or survival.

96. Fresh water. No situations have arisen to occasion the development of freshwater aquatic habitat on dredged material disposal sites. In riverine systems, dredged material is typically deposited on upland or diked disposal sites or placed on low energy bars where erosion occurs gradually. In the Great Lakes, the only large freshwater area other than riverine systems that is routinely dredged, material is placed in diked containment areas because of the potential presence of contaminants. Therefore, no references were found in the literature concerning experimental establishment of vegetation for development of freshwater aquatic habitat.

Marsh habitat development

97. Marsh habitat development is the best understood of all dredged material habitat development alternatives. This is due to the facility and economy with which dredged material marshes can be constructed. Marsh development technology is sufficiently advanced for the design and construction of productive systems at costs little above the cost of normal project operations (Smith 1978).

98. Marshes are defined as wetland areas dominated by nonwoody vegetation, and include tidal freshwater and saltwater marshes, and relatively permanently inundated freshwater marshes (Smith 1978). Natural invasion of plants can be expected if the environmental requirements for a marsh community are met and there is an abundant source of propagules nearby. The principal disadvantages of natural invasion are (a) it may occur too slowly (perhaps over a period of years), and (b) undesirable plant species may predominate (Environmental Laboratory 1978). In situations where cover is needed for rapid stabilization, or where environmental conditions are harsh, planting is desirable. Species selected for artificial propagation are usually

representative of the native flora in adjacent marshes. Most exotic species are readily overcome by local natural invaders.

99. According to Lunz et al. (1978), the primary determinant of plant distribution on marsh sites is the magnitude, frequency, and duration of flooding. They also found that species diversity increased with decreased frequency of inundation, a typical marsh characteristic.

100. Common problems encountered in planting for marsh habitat development are high wave or current energies, and coarse-textured sediments that are low in nutrients. When wave energies are extreme, protective and retaining structures are constructed. However, if the foundation is weak or unstable (as at Rennie Island in Grays Harbor, Washington), marsh development may not be feasible and the project may have to be abandoned (Vincent 1978).

101. The most important physical characteristic of dredged material in revegetation with marsh plants is texture, which is highly correlated with nutrient levels. Fine-textured materials tend to be rich in nutrients and, therefore, do not require fertilization. Coarse-textured materials, especially those occurring where rapid cover is needed, require fertilization. An all-purpose fertilizer [e.g., 13-13-13 (NPK)] is usually applied at a rate based on sediment analyses. Spring application followed by a midsummer application has resulted in more evenly distributed available nutrients than use of slow-release fertilizers (Environmental Laboratory 1978). Even with application of fertilizer, rapid leaching of coarse-textured dredged material during periods of high rainfall or flooding can minimize nutrient availability (Lunz et al. 1978).

102. Like nutrient levels, sediment microbial levels vary with sediment texture. In one study, textural differences accounted for 80 percent of the variance in bacterial numbers of intertidal sediments with coarse material exhibiting fewest microorganisms (Dale 1974).

103. Landin (1978) listed 115 marsh plant species for use in wetland development based on their ability to grow in dredged material, to stabilize the substrate, and to provide for wildlife needs. Most of these plants have not been investigated for occurrence of mycorrhizae.

Upland habitat development

104. Upland habitat is a very broad category of terrestrial communities characterized by vegetation that is not normally subjected to inundation. Types may range from bare ground to mature forests. Regardless of the

condition or location of a disposal area, considerable potential exists to convert it to a more productive habitat. The greatest potential is for enhancement of residential areas, and development of parks, recreational areas, and wildlife habitat. Dredged material disposal sites tend to become vegetated regardless of reclamation or revegetation efforts. However, well-planned and managed habitat development adds little to the cost of the disposal operation while greatly improving site quality and productivity, and dramatically increasing the rate of reclamation (Smith 1978).

105. Variations in elevation and moisture levels are important factors in determining species survival. Coastal bermuda grass (*Cynodon dactylon* var. *alecia*), bitter panic grass (*Panicum amarum*), live oak (*Quercus virginiana*), winged sumac (*Rhus copallina*), and wax myrtle (*Myrica cerifera*) temporarily stabilized a planted upland disposal site on Bolivar Peninsula, Galveston Bay, Texas (Allen et al. 1978). (The site was later naturally colonized by other species.) The most tolerant of these species to variations in elevation and moisture were live oak, winged sumac, and wax myrtle. Salt cedar (*Tamarix gallica*) and sand pine (*Pinus clausa*) performed poorly on the higher, drier soils suggesting that these species might be more suitable in areas where soil moisture was more uniform (Allen et al. 1978).

106. Typical site preparation for upland revegetation includes liming, fertilizing, seeding or sprigging, and perhaps mowing to control undesirable invading species. Fertilization has proven especially beneficial in establishment of vegetation on upland disposal sites. Fertilization of upland sites yielded higher aboveground biomass, and more vigorous, competitive legumes (Clairain et al. 1978). Plant growth, density, and other performance factors for grasses were greatly increased with repeated applications of fertilizer (Allen et al. 1978). In a revegetation study at Miller Sands on the Columbia River, Oregon, red clover (*Trifolium pratense*), white clover (*T. repens*), hairy vetch (*Vicia villopa*), tall fescue (*Festuca elatior*), Oregon bentgrass (*Agrostis oregonensis*), barley (*Hordeum vulgare*), and tall wheatgrass (*Agropyron elongatum*) became well established in fertilized meadows following seeding, but fertilization had no long-range impact on survival (Clairain et al. 1978). At the Bolivar Peninsula site, coastal bermuda and bitter panic grasses grew better when fertilized, but fertilization had no effect on their survival (Allen et al. 1978). In both studies fertilization encouraged invasion and competition by undesirable plant species. At the Miller Sands

site, the most intense competition was from common velvetgrass (*Holcus lanatus*) and rat-tail fescue (*Festuca myuros*), but common broadleaf and moss species also invaded.

107. On sites where soils retain little moisture and are relatively infertile, the goal of maintaining a highly productive area probably cannot be achieved without continued maintenance, including periodic discing, seeding, and fertilization. Such intensive efforts may not be cost-effective.

108. Very few references were found in the literature concerning microbial flora establishing on or associated with dredged material. In studies of chemical composition of the material, its leachates and interstitial waters, mention is sometimes made of microbial processes that were either substantiated or surmised. The only other mentionings of specific microflora concerned nitrogen fixation and, in one instance, plant disease. At a Nott Island, Connecticut, site, grasses were more successful colonizers than clover (Barry et al. 1978). Investigators attributed the failure of clover to the absence of nitrogen-fixing bacteria. None were added to seeds; none were found naturally present in the dredged material; and no nodulation occurred. At Miller Sands, hairy vetch plantings that had been successful for one full growing season and into the spring of a second declined dramatically in ground cover and biomass as a result of black stem rust disease (*Ascochyta imperfecta*) (Clairain et al. 1978).

109. No mention was made in the literature of mycorrhizal associations of plants used in revegetation of dredged material disposal sites. However, many of the plants used have been shown to have mycorrhizal associations (Tables A1-A3).

Reforestation

110. Mycorrhizae were discovered about a century ago, but their beneficial effects have been realized and exploited for only the last 20 to 25 years (Patrick 1979). The forest industry was the first to recognize the potential use of mycorrhizal associations. Most trees have a complement of mycorrhizal fungi upon which they depend for efficient nutrient and water absorption. Trees that have lost their mycorrhizal fungi frequently become stunted due to decreased absorption, especially if the soil in which they are

growing is nutrient-deficient. Therefore, good reforestation practices require the incorporation of mycorrhizae into seedling production methods.

Tree seedlings

111. Beneficial effects of mycorrhizae on tree seedlings are the direct or indirect results of the intimate association of mycorrhizal fungi with tree root systems. Mycorrhizal fungi increase root surface area and root collar diameter, promote efficient water and nutrient absorption, increase plant resistance to adverse soil conditions, and afford protection from some root pathogens (Ruehle 1980b). Indirect effects of increased root efficiency are seedling vigor; increased number of lateral shoots from stems; greater stem weight, biomass, and height; enhanced growth rate in low fertility soils; and, in general, better field performance.

112. Roots. Mycorrhizal fungi benefit the host root system in several ways. *Lactarius rufus*, an ectomycorrhizal fungus of spruce (*Picea sitchensis*), increased root weight of seedlings and stimulated the production of short roots (Alexander 1981). An experimental formulation of *Pisolithus tinctorius* increased the number of roots per cutting, the average root length, the total root length, and the root dry weight of inoculated poplar (*Populus* spp.) hybrids (Navratil and Rochon 1981). Increases in root collar diameter in inoculated versus uninoculated seedling have been shown in sweetgum (Barham 1978; Kormanik et al. 1981), loblolly pine (Ruehle 1982), and black oak (Dixon et al. 1981a) (Figures 4 and 5).

113. Root growth rate of red pine (*Pinus resinosa*) seedlings above a specific threshold level progressively inhibited a formulation of *Pisolithus tinctorius* (Sohn 1981). Not only did rapid root growth rate reduce mycorrhizae formation, but, conversely, mycorrhizae formation was capable of reducing root growth rate. These results suggest a feedback mechanism that controls the plant/fungus relationship.

114. Stems. Enhancement of shoot development has also resulted from mycorrhization of seedlings. Shoot weight and number of lateral shoots from stems increased in mycorrhizal seedlings (Alexander 1981). VAM development increased stem weight 2- to 80-fold over nonmycorrhizal seedlings of the following seven forest species: red maple (*Acer rubrum*), sweetgum, black walnut (*Juglans nigra*), green ash (*Fraxinus pennsylvanica*), boxelder (*Acer negundo*), sycamore (*Platanus occidentalis*), and black cherry (*Prunus serotina*) (Kormanik et al. 1982). Sweetgum seedlings treated with a mixture of two mycorrhizal

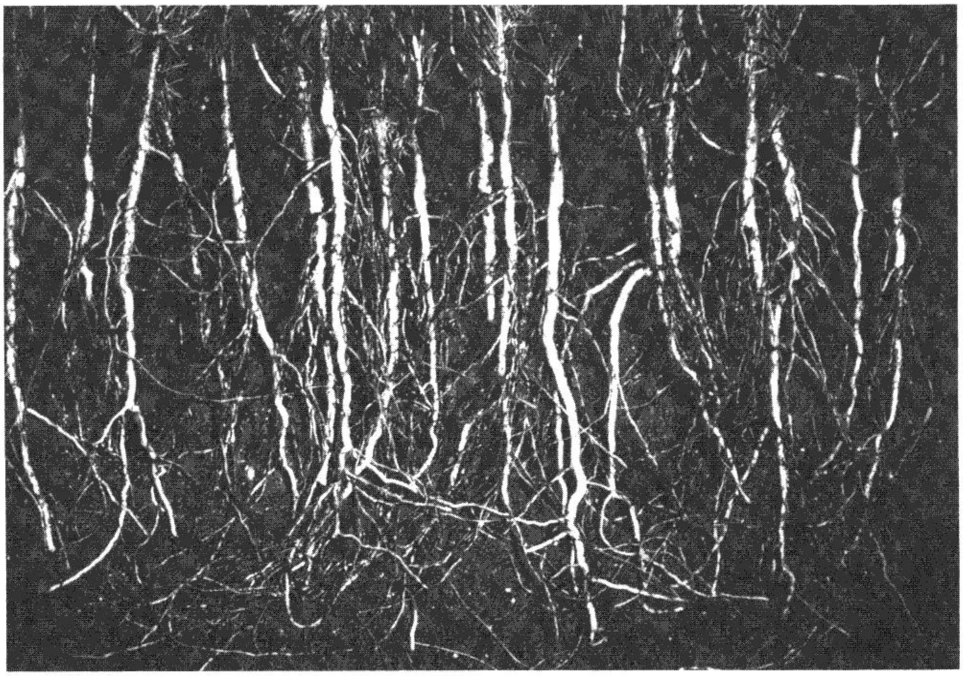

Figure 4. Root systems of loblolly pine seedlings inoculated naturally by mycorrhizal fungi present in the soil

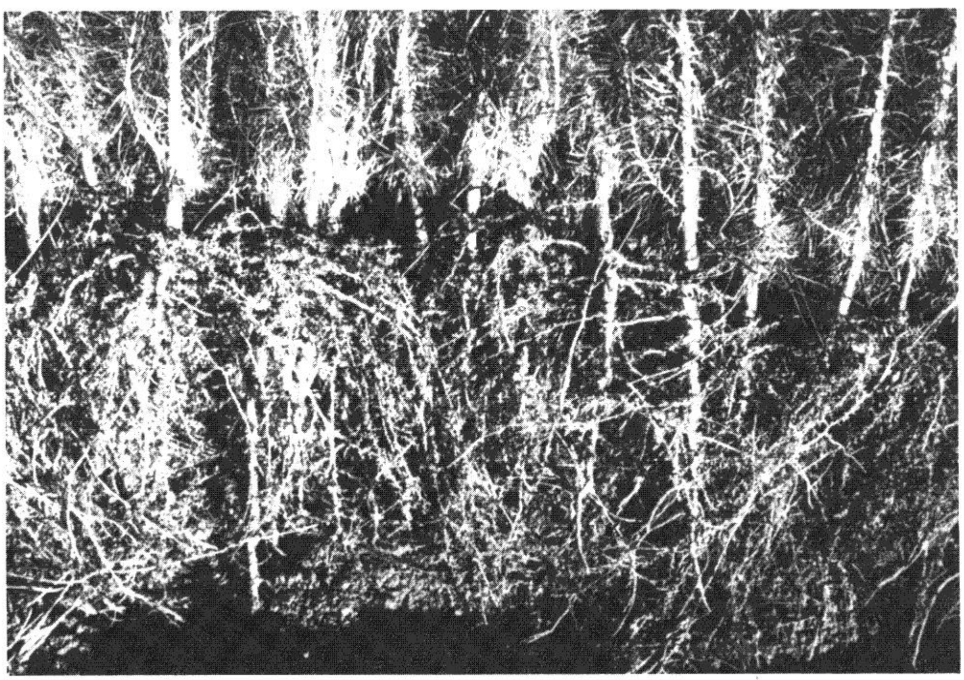

Figure 5. Root systems of loblolly pine seedlings planted as in Figure 4 above, but inoculated with the mycorrhizal fungus *Pisolithus tinctorius*

fungi (*Glomus mosseae* and *Glomus etunicatus*) in various concentrations exhibited significantly greater biomass, height, and stem diameter at each of four fertilizer levels (140, 280, 560, and 1120 kg/ha of 10-10-10) than did untreated seedlings (Schultz et al. 1979). The dramatic impact of inoculation with mycorrhizae is shown in Figures 6 and 7.

115. Nutrient adsorption. Mycorrhizae have been demonstrated to enhance nutrient and water uptake by seedlings of several forest trees. Phosphorus and zinc significantly increased in pine seedlings (*Pinus caribaea* var. *hondurensis*) inoculated with mycorrhizae (Hart et al. 1980). Foliar phosphorus and plant dry weight were increased in sycamore seedlings inoculated with *Glomus fasciculatus* (Pope 1980).

116. Adverse soil conditions. Improvements in survival and growth of tree seedlings in adverse soil conditions have been extensively investigated in relation to reclamation of disturbed sites (Figures 6 and 7). These studies are discussed in paragraphs 130-138. Generally, mycorrhization has been shown to enhance seedling growth and survival in adverse soil conditions. Seedling survival has been improved by mycorrhization in coal spoils high in aluminum, sulfur, manganese, copper, and iron (Marx 1975). Specific instances have been found in which mycorrhizal plants were not only tolerant of certain heavy metals, but capable of sequestering and storing them, thereby detoxifying soils (Maronek et al. 1981). Endomycorrhizae tend to be prevalent in low fertility soils, especially when nitrogen and phosphorus are low. Loblolly pine seedling growth has been increased in low fertility soils by inoculation with *Pisolithus tinctorius* (Marx and Barnett 1974).

117. Mycorrhizae may also play an important part in development of soil structure and in soil stabilization. Mycorrhizae hyphae contribute to aggregation of soil particles 2 mm in diameter (Tisdall and Oades 1979), and bind sand grains for stabilization of dunes and sandy soil (Clough and Sutton 1978).

118. Fertilizers. Effects of phosphorus and nitrogen fertilizers on mycorrhizal growth and development are discussed in Part III. Mycorrhizal sweetgum seedlings had significantly greater biomass, height, and stem diameter at each of four fertilizer levels, but mycorrhization of the fertilized seedlings did not increase nitrogen, phosphorus, potassium, or magnesium concentrations in leaves, stems, or roots (Schultz et al. 1979). The rate of fertilizer release may influence mycorrhizal development. A greater

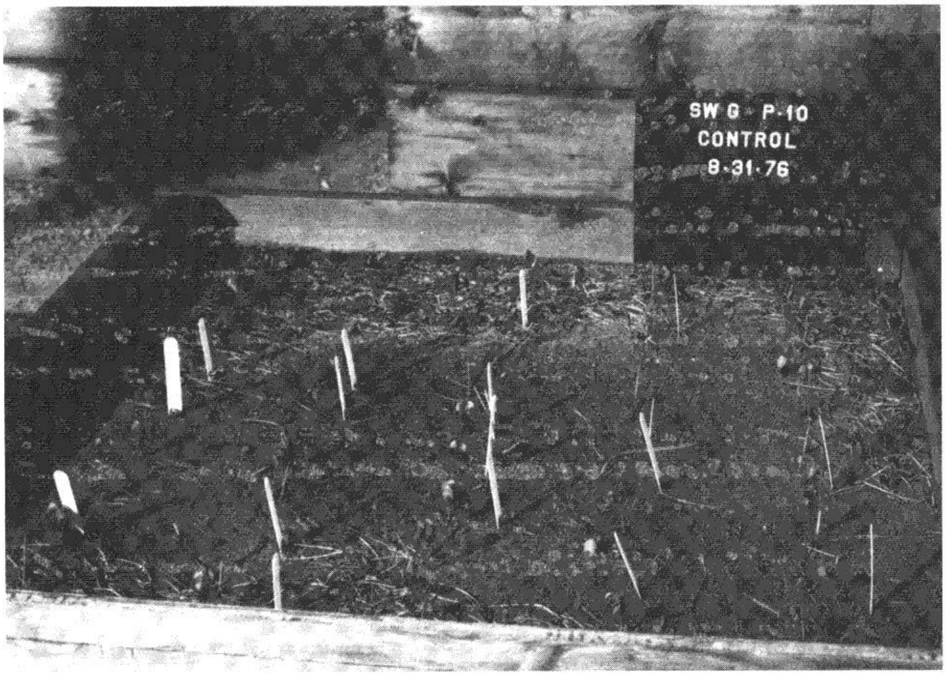

Figure 6. Five-month-old sweetgum seedlings grown from seeds in fumigated nursery soil

Figure 7. Five-month-old sweetgum seedlings grown from seeds in fumigated nursery soil and treated with VAM

percentage of roots became mycorrhizal when treated with 4.5 kg/m^3 of a slow release fertilizer than when treated with 1.9 kg/m^3 of a rapid release fertilizer (Maronek et al. 1981).

119. Container-grown seedlings. Most investigators have found that mycorrhization of containerized tree seedlings improves survival and growth at outplanting (Cordell and Marx 1980; Dixon et al. 1981a, 1981b; Johnson 1980). The success of containerized mycorrhizal seedlings was attributed to an increased number of lateral roots (Johnson 1980), larger size of mycorrhizae (Dixon et al. 1981b; Mexal 1980), more infection sites on container-grown seedlings (Johnson 1980), and increases in the extent of infection (Cline and Reid 1982; Ruehle and Brendemuehl 1981; Ruehle et al. 1981a).

120. Outplanting. The most important test of the value of mycorrhizal inoculation of tree seedlings is their subsequent success when outplanted. An extensive survey of the literature concerning the value of inoculation of container-grown and bare-root nursery seedlings with specific mycorrhizal fungi is given by Marx (1978). Most studies show that inoculation generally improves survival, quality, and growth of seedlings (Cordell and Marx 1980; Kelley 1979; Mexal 1980; Ruehle and Brendemuehl 1981; Ruehle et al. 1981).

Forest ecology

121. Nutrients. Mycorrhizae exert other influences on the forest ecosystem in addition to beneficial effects on trees per se. The fine mycorrhizal roots of Pacific silver fir (*Abies amabilis*) contribute approximately 45 percent of the net primary production (both biomass and nutrient distribution) in young stands and 75 percent in mature stands (Vogt et al. 1982). Mycorrhizae account for 50 percent of the annually assimilated biomass and 43 percent of the annually released nitrogen in a Douglas fir ecosystem (Fogel 1980). These transfers are five times larger than the releases from litter fall or litter decomposition.

122. Drought. Mycorrhization of seedlings enhances drought resistance during periods of soil water deficits (Aldon 1975; Dixon et al. 1980; Theodorou 1978; Worley and Hacskaylo 1959). White oak seedlings (*Quercus alba*) inoculated with *Pisolithus tinctorius* showed increased drought resistance, greater capacity to absorb water, and recovery to significantly higher levels when soil water was resupplied than nonmycorrhizal seedlings (Dixon et al. 1980). Fourwing saltbush (*Atriplex canescens*) grown in semiarid areas of New Mexico where precipitation is less than 250 mm per annum showed increased

survival when inoculated with *Glomus mosseae* as compared to uninoculated plants (Aldon 1975). *Cenococcum graniforme* has been found to form mycorrhizae under severe moisture stress. *Rhizopogon luteolus* and *Suillus granulatus* increased survival of Monterey pine (*Pinus radiata*) during very dry conditions following planting (Theodorou 1978). *Pisolithus tinctorius* is often found in drought conditions in coal spoils (Theodorou 1978). Changes in soil water potential may have less impact on absorption processes than effective penetration of soil by mycelial strands and hyphae in offsetting lowered transfer of ions to roots under conditions of low soil moisture (Reid and Bowen 1979).

123. Flood tolerance. Mycorrhizal fungi do not seem as well adapted to flooded soils as to soils under low moisture stress. Maronek et al. (1981) consistently found poorer mycorrhizal development on conifer and hardwood species inoculated with *Pisolithus tinctorius* growing in poorly drained container media. However, both *Hymenogaster alnicola* and *Lactarius obscuratus* form mycorrhizae on alder (*Alnus* sp.) in continuously wet soils (Trappe 1977), and blackgum (*Nyssa sylvatica*) seedlings grown for a year under flooded conditions established endomycorrhizal associations with *Glomus mosseae*, while showing significant increases in biomass over nonmycorrhizal controls (Keeley 1980).

124. Disease resistance. Many investigators have observed increased resistance to disease in mycorrhizal plants as opposed to nonmycorrhizal plants. All nonmycorrhizal roots of shortleaf pine became infected with *Phytophthora cinnamomi*, but those with well-formed mantles of *Thelephora terrestris* (29 μm thick) or *Pisolithus tinctorius* (76 μm thick) were resistant to infection (Marx 1970a, 1970b). The thick mycorrhizal mantle may provide a physical barrier to potentially invasive pathogens. Five types of naturally occurring ectomycorrhizae of shortleaf pine with mantles ranging from very thin (5-8 μm) to thick (47-52 μm) were resistant to pathogenic infections, while nonmycorrhizal roots were 100 percent infected with *Phytophthora cinnamomi* (Marx and Davey 1969a).

125. Other investigators suggest that selective pressure on the rhizosphere microflora exerted by host/fungus interactions confer disease resistance to the plant root system. For example, Oswald and Ferchau (1968) found that certain species of bacteria in the mycorrhizosphere occurred only in association with mycorrhizae while other species were associated with nonmycorrhizal roots. Bacteria growing on mycorrhizal roots of yellow birch (*Betula lutea*) have complex nutritional requirements, while those growing on

nonmycorrhizal roots need only minerals and glucose (Katznelson et al. 1962). Root pathogens (*Pythium* and *Fusarium* spp.) were the predominant fungi in nonmycorrhizal roots, but were absent in mycorrhizal roots, and the incidence of *Cylindrocarpon* sp. was reduced from 38 percent in nonmycorrhizal roots to 21 percent in mycorrhizal roots.

126. Chemical inhibitors (e.g., antibiotics) have also been implicated in disease resistance of mycorrhizal roots (Maronek et al. 1981; Marx 1972), and the antibiotic diatretyne nitrile has been identified in the ectomycorrhizal association between *Leucopaxillus cerealis* and shortleaf pine seedlings (Marx and Davey 1969b). A less direct effect of inhibitory substances may be the control of the fungal symbiont by the plant root system. Maintenance of a balanced relationship between fungus and plant may simultaneously provide protection against pathogens (Maronek et al. 1981). The use of benomyl, a systemic fungicide, together with the ectomycorrhiza *Pisolithus tinctorius* in combatting brown-spot needle blight (*Scirrhia acicola*) on young longleaf pine seedlings (*Pinus palustris*) has been successful (Kais et al. 1981). The effect of the ectomycorrhiza was stimulation of early height growth in seedlings, which hastened them through their most susceptible period, while the benomyl offered protection from the pathogen during the same period.

Current research

127. The effectiveness of mycorrhizae in enhancing growth of high value woody plants has been so well documented that government and private forest services are sponsoring research and development of mycorrhizal fungi for large-scale use. At the US Department Agriculture Forest Service Institute for Mycorrhizal Research and Development at Athens, Ga., scientists are conducting nationwide tests on the potential use of mycorrhizal fungi to improve forest productivity (Marx 1978; Marx and Beattie 1977). The National *Pisolithus tinctorius* Mycorrhizae Evaluation was expanded in 1978 to include 33 bare-root nurseries in 28 states and container-grown seedling nurseries in 8 states and Canada. The objective was to compare the effectiveness of inoculum produced by the Institute with inoculum produced on a larger scale by Abbott Laboratories, Chicago, Ill. Effectiveness of the inocula in stimulating feeder root formation, seedling growth and quality, and tree survival and growth in subsequent field outplantings was examined. The two inocula were found to be comparable and very effective on a variety of conifers and some hardwoods in both bare-root and container seedlings (Cordell et al. 1978). A

commercial formulation of *Pisolithus tinctorius* has the potential to improve nursery and field performance of numerous tree species throughout the world. The same principles are being expanded to include additional hardwoods (Marx and Beattie 1977).

128. The Natchez Forest Research Center, established in 1979 by International Paper Company, is surveying and sampling areas within the company's land holdings to determine mycorrhizal fungi that are most effective on certain tree species. The company will consider large-scale production of promising ectomycorrhizal fungi by another commercial firm (Patrick 1979).

129. In the future tree farmers will be able to request seedlings tailored with mycorrhizae from state and private nurseries. Any added cost should be offset by greater survival and growth potential (Marx and Beattie 1977). Mycorrhization for the improvement of reforestation practices is already a reality.

Reclamation

130. Increased environmental awareness over the last decade has necessitated the reclamation of strip-mined areas and waste disposal sites. Mycorrhizal associations of trees, shrubs, and herbaceous plants are being examined because of their potential contribution to the rapid and successful re-establishment of vegetation in these areas. Since mycorrhizal fungi are more or less restricted to the uppermost layer of the soil, any land-disturbing activity that mixes or inverts soil from deeper horizons has the potential of reducing the mycorrhizal fungus population below effective levels (Schwab and Reeves 1981).

Strip-mined sites

131. Strip-mining of coal is one example of soil-inverting activity. Not only are mycorrhizae diluted or destroyed in such sites, but coal spoils are deficient in micronutrients and frequently contain substances toxic to plants (Berry and Marx 1977). If abandoned, most strip-mined sites become revegetated naturally and the volunteer species usually develop mycorrhizal associations by the end of the first year (Barnhill 1981; Daft and Hacskaylo 1976; Riley and Brown 1978; Rothwell and Vogel 1982; Shuffstall and Medve 1979). However, the extent of mycorrhization and seedlings growth is improved when mycorrhizal plants are used (Aldon 1975, 1978; Barnhill 1981; Berry

1982b; Daft and Hacskaylo 1977; Daft et al. 1975; Lambert and Cole 1980; Lindsey et al. 1977; Marx 1975, 1980) (Figures 8 and 9). Maximum benefits can be achieved when host genotype and specific mycorrhizal fungus are carefully matched (Berry 1982b), when the reclamation site is graded prior to planting to disperse fungal propagules (Ponder 1979), and when a "starter" pellet of fertilizer is used to stimulate seedlings (Marx 1977a).

132. Strip-mining of kaolin presents some of the same problems to reclamation efforts as posed by strip-mining of coal. Kaolin spoils are highly variable in pH and in physical and chemical characteristics. A major problem is low cation exchange capacity, a result of low organic matter. Sewage sludge has been used to provide organic matter, and has effectively stimulated growth and mycorrhizal development (Berry and Marx 1977). Fertilization tends to decrease loblolly pine seedling survival on kaolin spoils regardless of mycorrhizal condition (Marx 1977c).

Waste disposal sites

133. Limited studies have been conducted on mycorrhizal effects on revegetation of copper and iron tailings. No mycorrhizae developed on roots of willow (*Salix* spp.) and poplar in copper tailings (Harris and Jurgensen 1977). Tree tops and roots were stunted and showed limited survival. However, extensive mycorrhizal development occurred on iron tailings, and trees showed vigorous growth.

134. Mycorrhizal shrubs grown on processed oil shale were more effective in uptake of water and phosphorus, and had greater shoot biomass and height than nonmycorrhizal shrubs (Call 1981).

Other disturbed sites

135. Stabilization of various types of eroded soils can be enhanced by revegetation with mycorrhizal plants. Mycorrhizae have been found to be beneficial in the stabilization of barrier sand dunes (Clough and Sutton 1978; Daft and Hacskaylo 1977; Jehne and Thompson 1981; Koske and Halvorson 1981; Nicolson and Johnston 1979). The network of fungal hyphae are very common in the upper 0 to 20 cm of bare sand in the colonizing zone and the fungi intermesh sand grains to form aggregates that appear to stabilize loose sand (Jehne and Thompson 1981). Marked seasonal variations occur in levels of mycorrhization, with infections persisting into the winter and spring (Nicolson and Johnston 1979). Sand grain size has been shown to influence the mycorrhizal species that establish in dunes. Smaller grain size appears to favor fungi

Figure 8. Pitch pine (*Pinus rigida*) inoculated with ectomycorrhizae naturally occurring in nursery soil. Seedlings show second year growth on toxic (pH = 4.0) coal spoil in Tennessee

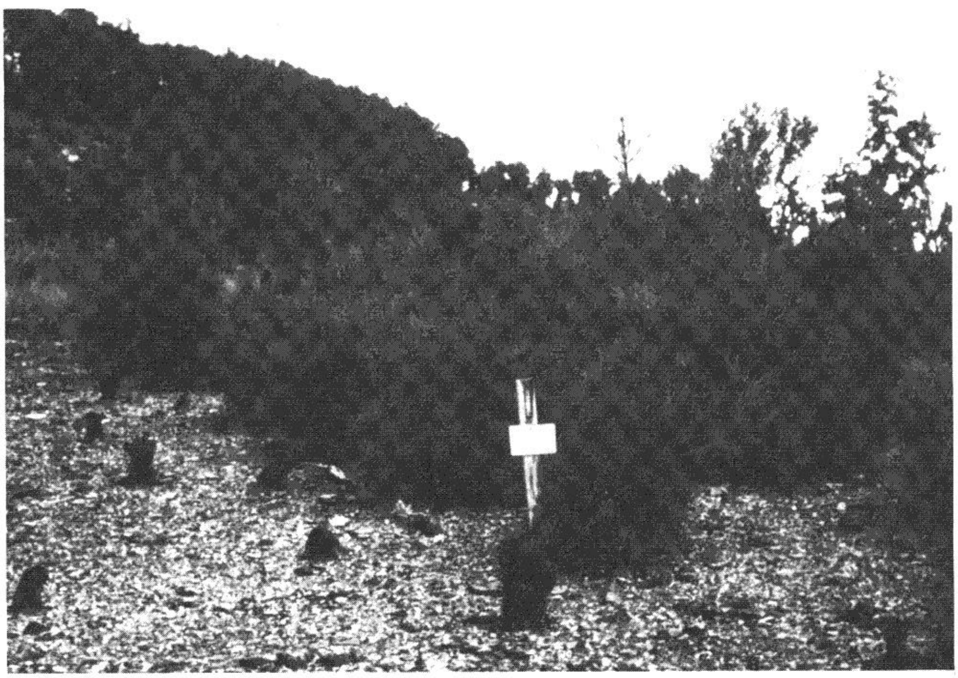

Figure 9. Pitch pine seedlings treated exactly as those shown in Figure 8, except inoculated with the mycorrhizal fungus *Pisolithus tinctorius*

(e.g. *Gigaspora gigantea*) that produce large spores (Koske and Halvorson 1981).

136. Mycorrhizal plants are more successful than nonmycorrhizal plants in erosion control in high elevation revegetation with woody species (Ledgard 1976), as protection against winter frost heave, and in pasture revegetation with clover (Powell 1980b).

137. Natural revegetation of disturbed surface soils is usually a slow process. Reeves et al. (1979) suggest that recovery is delayed because of the absence of viable propagules of mycorrhizal fungi. Without mycorrhizae, seedlings either do not survive, or their growth is significantly reduced. For example, old roadbeds constitute severely disturbed sites for reestablishment of plants. Studies have shown that less than 2 percent of the plants surviving on these sites were mycorrhizal, while 77 percent (Moorman and Reeves 1979) to 99 percent (Reeves et al. 1979) of plants in an adjacent undisturbed community were mycorrhizal. Successful reclamation of these sites depends on selecting and maintaining mycorrhizal fungi on colonizing plants (Reeves et al. 1979). Mycorrhizae improve establishment and growth of ornamental trees in an urban environment such as in narrow tree lawns and holes in concrete where tree root zones are restricted (Kuhns 1980).

138. Limited studies have been conducted on barrow pit reclamation with mycorrhizal pine seedlings. However, naturally occurring mycorrhizae (*Pisolithus tinctorius*) formed so abundantly on test sites that no nonmycorrhizal seedlings were available for comparison with treatments (Berry and Marx 1980).

Agriculture

Incidence of mycorrhization in crop plants

139. Most crop plants have naturally occurring populations of mycorrhizal fungi, and their beneficial effects have been documented for a wide range of agronomic species. The following tabulation lists examples:

Scientific Name	Common Name	Source
Allium cepa	Onion	Hirrel and Gerdemann (1980); Manjunath and Bagyaraj (1981); Nelsen (1981); Owusu-Bennoah and Mosse (1979)
A. porrum	Leek	Snellgrove et al. (1982)
Boutelous gracilis	Grama	Allen (1982); Allen et al. (1981)
Capsicum annuum	Bellpepper	Hirrel and Gerdemann (1980)
Citrus aurantium	Sour orange	Krikun and Levy (1980); McGraw and Schenck (1981); Timmer and Leyden (1979)
C. jambhiri	Rough lemon	Krikun and Levy (1980); Levy and Krikun (1980); Levy et al. (1981); Menge et al. (1977)
C. reticulata	Cleopatra mandarin	Krikun and Levy (1980)
Eleusine coracana	Millet	Bagyaraj and Manjunath (1980)
Elymus spp.	Rye	Hall and Armstrong (1979); Powell (1979a)
Glycine max	Soybean	Bethlenfalvay et al. (1981), (1982c); Carling and Brown, 1980; Carling et al. (1979); Gianinazzi-Pearson et al. (1981)
Gossypium hirsutum	Cotton	Bagyaraj and Manjunath (1980)
Hordeum vulgare	Barley	Jensen (1982); Owusu-Bennoah and Mosse (1979); Powell (1981)
Lotus uliginosus	Grassland maku	Hall and Armstrong (1979); Powell (1982a)
Lycopersicon esculentum	Tomato	McGraw and Schenck (1981)
Malus spp.	Apple	Covey et al. (1981); Greene et al. (1982); Plenchette et al. (1981)
Manihot esculenta	Cassava	Kang et al. (1980); Zaag et al. (1979)
Medicago sativa	Alfalfa	Lambert et al. (1980c); O'Bannon et al. (1980); Owusu-Bennoah and Mosse (1979)

(Continued)

Scientific Name	Common Name	Source
Persea americana	Avocada	Menge et al. (1980)
Poncirus trifoliata	Troyer citrange	Menge et al. (1977), (1982)
Prunus persica	Peach	McGraw and Schenck (1981); Strobel et al. (1982); Covey et al. (1981); Green et al. (1982); Plenchette et al. (1981)
Rubus idaeus	Raspberry	Hughes et al. (1979); Morandi et al. (1979)
Sorghum bicolor	Sorghum	Krishna and Bagyaraj (1981)
Trifolium spp.	Clover	Abbott and Robson (1978); Buwalda (1980); Hall and Armstrong (1979); Hayman and Mosse (1979); Powell (1982a); Rangeley et al. (1982); Smith (1982); Sparling and Tinker (1978b)
Vaccinium angustifolium	Blueberry	Reich et al. (1982)
Vigna unguiculata	Cowpea	Bagyaraj and Manjunath (1980)
Zea mays	Corn	Covey et al. (1981)

Beneficial effects of mycorrhization

140. Plant growth. The beneficial effects of mycorrhizae on agronomic species are similar to their effects on other plant species. The mycorrhizae increase shoot height, leaf surface area, root volume, stem diameter, and dry weight more than fertilization (Plenchette et al. 1981). They stimulate the growth rate of Troyer citrange (Menge et al. 1982), siratro (*Macroptilium atropurpureum*) (Lopes et al. 1980), clover (Abbott and Robson 1978; Hayman and Mosse 1979), and axenically propagated raspberry (Morandi et al. 1979). They stimulate root activity in eucalyptus (*Eucalyptus st-johnii*) (Chilvers and Gust 1982a), eliminate stunting and nutrient deficiency in several citrus species (Menge et al. 1977), and increase vegetative and reproductive growth in sour orange, tomato, peach, chrysanthemum (*Chrysanthemum morifolium*), and podocarpus (*Podocarpus macrophyllum*) (McGraw and Schenck 1981).

141. Phosphorus uptake. Mycorrhizae increase nutrient uptake, particularly phosphorus, in many agronomic species. Inoculation of ryegrass with *Glomus tenuis* increased phosphorus uptake to levels higher than found with indigenous mycorrhizae, suggesting that specific host-fungus

relationships are important, and that supplementing existing mycorrhizae populations may be helpful (Powell 1979a). Mycorrhizae provide plants with more efficient means of exploiting labile phosphorus pools in the soil (paragraphs 74-81) (Gianinazzi-Pearson et al. 1981). Studies of phosphorus absorption by clover (Smith 1982), cassava (Kang et al. 1980; Zaag et al. 1979), red raspberry (Hughes et al. 1979), and soybeans (Bethlenfalvay et al. 1982c) showed that mycorrhizal plants were more efficient than nonmycorrhizal plants in phosphorus absorption. Enhancement of plant growth by mycorrhizae in phosphorus-deficient soils has been demonstrated for alfalfa (O'Bannon et al. 1980), citrus (Krikun and Levy 1980), cotton, cowpea, and finger millet (Bagyaraj and Manjunath 1980).

142. Phosphorus uptake by grasses is frequently less affected by mycorrhizae because their fine, many-branched root systems permit efficient absorption. Therefore, grasses are not usually enhanced by mycorrhizae until soil levels of phosphorus are severely depleted (Sparling and Tinker 1978a). Effects of mycorrhizae on white clover growth are minimal and confined to the lowest soil phosphate levels (Crush and Caradus 1980).

143. Mycorrhizal inoculation of crop plants may provide an alternative to rising energy and fertilizer costs by increasing crop yields while reducing fertilizer and energy input (Menge 1983; Krishna and Bagyaraj 1981). Mycorrhization in combination with reduced applications of phosphate fertilizers has been shown to be efficient in stimulating plant growth in clover (Powell 1982a; Sparling and Tinker 1978b), soybeans (Bethlenfalvay et al. 1981), and lotus (*Lotus penduneulatus*) (Powell 1982a). Mycorrhizae do not seem to be inhibited by fertilization until high levels are reached.

144. Uptake of other nutrients. In addition to improving phosphorus absorption, mycorrhizae have been shown to improve translocation of carbon from shoots to roots (Snellgrove et al. 1982), and increase uptake of copper (Jensen 1982) and zinc (Jensen 1982; Swaminathan and Verma 1979).

145. Water transport. Mycorrhizae contribute to water transport in plants by increasing the absorptive surface of roots (Allen 1982). Effects of mycorrhizae on the plant-water relationship are not limited to increased water absorption, but also include increased transpiration rates (Allen et al. 1981; Levy et al. 1981). The more rapid recovery of mycorrhizal than nonmycorrhizal lemon seedlings from drought stress has been attributed to stomatal regulation rather than root resistance (Levy and Krikun 1980). Mycorrhizal plants have

also been found more resistant to drought than nonmycorrhizal plants (Nelsen 1981). The inhibitory effects of salinity on onions and bellpeppers inoculated with mycorrhizal fungi were less than on uninoculated controls, suggesting that mycorrhizae may contribute to salt tolerance (Hirrel and Gerdemann 1980).

146. Disease resistance. The role of mycorrhizae in plant disease resistance has been investigated more extensively in trees than in agronomic species. However, some evidence exists for mycorrhizal-induced resistance to several pathogens of agronomic species. Several species of mycorrhizae have been shown to reduce infections by *Thielaviopsis basicola* on tobacco (*Nicotiana tabacum*) and alfalfa; *Fusarium oxysporum* form species *lycopersii* on tomato; *Phytophthora megasperma* var. *sojae* on soybean; *Pyrenochaeta terrestris* on onion; and *Rhizoctonia solnani* and *Pythium ultimum* on poinsettia (*Euphorbia pulcherrima*) (Schenck and Kellam 1978). Several species of VAM have been found to suppress root-knot nematodes on tomato, cotton, soybean, tobacco, carrot (*Daucus carota* var. *sativa*), and oats. Most mycorrhizal plants had fewer galls and/or larvae than nonmycorrhizal plants (Schenck 1981). *Gigaspora margarita* suppressed reproduction of the nematode *Meloidogyne incognita* in tests where the fungus improved growth of peaches (Strobel et al. 1982).

147. Competitive ability. Mycorrhizae improve the competitive ability of plants. Mycorrhizal clover shoot yield and phosphorus absorption increased while the clover successfully competed with ryegrass (Buwalda 1980).

148. Protection from toxic substances. There is limited evidence that VAM afford protection from toxic substances. Corn was protected from arsenic toxicity by VAM (Covey et al. 1981).

PART V: POTENTIAL USE OF MYCORRHIZAE FOR REVEGETATION OF DREDGED MATERIAL DISPOSAL SITES

Enhancement of Nutrient Absorption

149. One of the greatest potential benefits in mycorrhization of plants used for revegetation of dredged material disposal sites is more efficient nutrient absorption. Mycorrhizal fungi are not only capable of improving nutrient absorption in nutrient-deficient soils, but can also increase the availability of soil-bound nutrients. Extensive evidence from the literature also substantiates the ability of mycorrhizae to promote the early, successful establishment of vegetation, an important consideration when rapid stabilization and cover of dredged material disposal sites is necessary.

Phosphorus

150. Phosphorus availability is frequently a problem in dredged material disposal sites. In some cases total phosphorus is low and in others, especially when pH is extreme, insoluble phosphate complexes are formed that render the often ample phosphorus supply unavailable for uptake by plants. Mycorrhizal fungi are efficient providers of phosphorus to their hosts. Mycorrhizal fungi can make phosphorus available to plants even when it is soil-bound. In most dredged materials, when high phosphorus levels occur, the phosphorus is in bound complexes which are not inhibitory to mycorrhizae. Even addition of phosphate fertilizers has not limited mycorrhizal fungi until extremely high levels have been reached (Powell 1980a, 1980c). Mycorrhizae have tremendous potential for improving phosphorus absorption by plants in dredged material and for limiting the amount of phosphate fertilizer required for the early, successful establishment of desirable plant species.

Nitrogen

151. Nitrogen is deficient in most dredged material. Submergence favors reactions that remove nitrogen from sediments. Continued nitrogen decreases in dredged material after placement on disposal sites have been demonstrated (Lunz et al. 1978). No evidence was found in the literature indicating that mycorrhizal fungi enhance nitrogen adsorption or availability to host plants, nor have mycorrhizal fungi been conclusively implicated in nitrogen fixation. However, low nitrogen levels (e.g. those commonly

occurring on dredged material disposal sites) have been shown to favor mycorrhizal development, which confers other survival advantages on the host plants.

Potassium

152. Potassium levels in dredged material are variable from site to site, but are frequently reduced as leaching progresses. Mycorrhizal fungi are capable of increasing potassium adsorption in deficient soils (Powell 1975). The positive response of plants on dredged material disposal sites to treatment with potassium-containing fertilizers suggests that assistance in potassium adsorption is beneficial and that mycorrhizae may be able to contribute to potassium adsorption in deficient dredged material.

Trace elements

153. Most essential micronutrients are present in sufficient quantities in dredged material, and their availability to developing plants should not usually be a problem. Studies of enhancement of micronutrient adsorption by mycorrhizal fungi are limited. Only absorption of zinc has been shown to improve in mycorrhizal as opposed to nonmycorrhizal plants (Stegnar et al. 1978). Excessive levels of zinc and copper have been shown to inhibit endomycorrhizae of citrus (Hepper and Smith 1976, McIlreen 1977 cited by Lambert et al. 1980a; Harris and Jurgensen 1977; Lambert et al. 1980a). Evidence was not found that such inhibition occurs among mycorrhizae of other plant species. No documentation of the role of mycorrhizae in absorption of other micronutrients was found.

Organic matter

154. Although evidence is limited, mycorrhizae seem to occur more frequently in mineral than in organic soils. Studies comparing growth and mycorrhization of white fir (*Abies concolor*) (Alvarez, Rowney, and Cobb 1979) and pine (Lee 1981) in mineral and organic soils show greater success in mineral soils. Fine-textured dredged material is potentially high in organic matter. Whether the organic matter levels present are sufficiently high to exert an inhibitory effect on desired mycorrhizal fungi is not known. Coarse-textured, sandy dredged material is low in organic matter and, therefore, conducive to mycorrhization.

Stabilization of Substrate

155. Often the most pressing problem in revegetation of dredged material disposal sites is rapid substrate stabilization. A good vegetative cover is desirable for this purpose. Even when physical retaining structures are necessary, vegetation establishment often provides excellent reinforcement. This is especially true where consideration is given to development or improvement of the site.

156. While the texture of dredged material varies considerably, many sites are composed of sandy material. Mycorrhizae enhance the establishment of vegetation in low-nutrient, sandy soils (Clough and Sutton 1978; Jehne and Thompson 1981; Koske and Halvorson 1981; Nicolson and Johnston 1979). The extensive external mycelium of *Glomus* sp. was the dominant factor in the aggregation of soil particles around long-leaved reedgrass (*Calamovilfa longifolia*) and beardgrass (*Andropogon* sp.) in Lake Huron sand dunes (Clough and Sutton 1978). Sand grains were attached to the fungal hyphae by an amorphous polysaccharide deposit. *Glomus fasciculatus* was a dominant agent in the aggregation of sand particles leading to sand stabilization at Tentsmuir National Nature Reserve, Fifeshire, Scotland (Nicolson and Johnston 1979). The mycorrhizal plants studied were European beachgrass (*Ammophila arenaria*) and *Agropyron junceiforme*.

157. Mycorrhizae may also enhance establishment of vegetation in dredged material composed primarily of silt and clay by extension of the plant root system and penetration of the substrate.

Availability of Water

158. Hydraulic conductivity of most dredged material is high compared to that of agricultural fields (Gupta et al. 1978). This means that materials placed in upland disposal areas may readily lose moisture by drainage. Therefore, upland disposal sites containing sandy material tend to have low water holding capacities and have water related problems when establishment of selected vegetation is important for development of specific habitat types (Allen et al. 1978; Clairain et al. 1978). Mycorrhizae enhance water absorption by plants (Allen 1982; Allen et al. 1981; Levy and Krikun 1980; Levy et al. 1981). This is most dramatically illustrated by drought resistance of

mycorrhizal plants (Aldon 1975; Dixon et al. 1980; Nelsen 1981; Reid and Bowen 1979; Theodorou 1978; Worley and Hacskaylo 1959).

Habitat Development

159. Mycorrhizae have the potential to play a major role in the early, successful establishment of desired vegetation on dredged material for the development of upland and marsh habitats. The potential for aquatic habitats is much less certain because very little research has been done concerning mycorrhization of aquatic vegetation.

Upland habitat

160. The greatest potential for immediate benefits from mycorrhization of plants on dredged material disposal sites exists on upland sites. Extensive research has been conducted by the forest industry and in reclamation of mining spoils to elucidate plant/mycorrhizal fungus interactions. Mycorrhizal occurrence, sensitivities, and beneficial effects on host survival and productivity have been well defined. Moisture levels, nutrients, and other soil conditions tolerated by mycorrhizae in upland areas have been well documented. Mycorrhizal plants have been demonstrated repeatedly to establish more quickly, survive longer, and grow more vigorously than nonmycorrhizal plants on disturbed sites. This information can be used to tailor mycorrhizal fungi to plant species already determined to be desirable for revegetation of dredged material.

Marsh habitat

161. Although mycorrhizal fungal spores survive and are capable of germinating under conditions of high moisture, waterlogging of soils has been demonstrated to surpress their function because of the anoxic conditions accompanying soil saturation. It is important, however, to point out that most studies of the effects of waterlogging on mycorrhizae were conducted with mycorrhizae of plant species normally adapted to terrestrial rather than marsh habitats. Studies conducted by Read et al. (1976) and Meador (1977) on marsh plants revealed infection levels that were low to absent. However, evidence of mycorrhizal infection of alder (*Alnus* spp.) and blackgum under intermittent to continuously flooded conditions was found in the literature (Trappe 1977;

Keeley 1980). Mycorrhizal blackgum has also been shown to exhibit increased biomass over nonmycorrhizal controls (Keeley 1980). Willows were found to be consistently mycorrhizal throughout the growing season in spite of anaerobic soil conditions as indicated by negative redox potentials (Marshall and Patullo 1981). Chaubal et al. (1982) reported mycorrhization of the following 11 freshwater marsh species,* some of which exhibited extensive VAM of roots:

Brassica juncea	Chinese mustard
Drosera sp.	Sundew
Drymaria cordata	West Indian chickweed
Galium rotundifolium	Bedstraw
Impatiens chinensis	Impatiens
Panicum brevifolium	Panic-grass
Plantago major	Common plantain
Polygonum capitatum	Knotweed
Rumex nepalensis	Dock
Sonchus sp.	Sow-thistle
Utricularia sp.	Bladderwort

162. Limited evidence from the literature suggests that mycorrhization has potential in revegetation of marshes, but initial efforts would require more basic research than is currently necessary for revegetation of upland areas.

Aquatic habitat

163. Literature concerning the mycorrhizal status of aquatic plants is extremely limited. The few investigations that have been documented show that some aquatic vascular plants are devoid of mycorrhizae (Khan 1974, 1979b; Read et al. 1976) and that others are slightly to extensively mycorrhizal (Bagyaraj et al. 1979b; Sondergaard and Laegaard 1977; Chaubal et al. 1982). Mycorrhizal aquatic species** are listed below:

Callitriche hamulata†	
Cyanotis cristata	
Eichhornia crassipes	Waterhyacinth
Eleocharis palustris†	Spike-rush

* Some authors classify certain of these species as aquatic rather than marsh.
** Some authors classify certain of these species as marsh rather than aquatic.
† Sondergaard and Laegaard (1977).

Hydrilla verticillata	Hydrilla
*Isoetes lacustris**	
*Littorella uniflora** (= *L. americana*)	
*Lobelia dortmanna**	Water-lobelia
*Nymphaea alba***	Water lily
*Paspalum dilatatum***	Dallis-grass
*Phragmites australis**	Common reed
*Polygonum hydropiper***	Common smartweed
*Rotala rotundifolia***	Rotala
Salvinia cucullata†	Water fern

164. Occurrence of mycorrhizae on aquatic plants may be dependent upon nutrient levels in the sediments (Sondergaard and Laegaard 1977). The heavy infection levels in *Littorella uniflora* (as high as 96 percent) and *Lobelia dortmanna* (as high as 55 percent) were attributed to the poorly developed root hairs of these plants and to phosphorus-deficient sediments. To determine the feasibility of revegetation of dredged material disposal sites with mycorrhizal aquatic plants, much more must be learned about mycorrhization of these plants.

165. No literature was found concerning the mycorrhizal status of aquatic marine plants.

Resistance to Salinity, Toxic Substances, and Disease

Salinity

166. Even though high salinity cannot be classified as contamination, many desirable plant species are salt-sensitive. Hunt et al. (1978) suggested that long periods (perhaps several years) of leaching may be required to remove excessive salinity from some dredged material disposal sites before revegetation can progress. However, most saline dredged material disposal sites do not contain sufficiently high salt levels to inhibit salt-tolerant plant species. Salt-tolerant plants usually invade all but extremely saline

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* Sondergaard and Laegaard (1977).
** Chaubal et al. (1982).
† Bagyaraj et al. (1979b).

disposal areas (Hoeppel et al. 1978). Salinity has little effect on the formation of VAM in plants adapted to saline soils (Hirrel and Gerdemann 1980). VAM have been found in saline environments associated with nine plant families including Fabaceae, Poaceae, and Solanaceae (Mason 1928; Fries 1944; Khan 1974, all cited by Hirrel and Gerdemann 1980). Two species of salt-sensitive plants, onion and bellpepper, have been demonstrated to be more salt-tolerant when mycorrhizal than when nonmycorrhizal (Hirrel and Gerdemann 1980). Therefore, mycorrhization may contribute to salt tolerance of plants in saline dredged materials thus expanding the number of plant species capable of establishing on saline disposal sites.

Toxic substances

167. The presence, types, and concentrations of contaminating toxins on dredged material disposal sites vary with site location. The availability of contaminants such as heavy metals, oil and grease, and organic pesticides to vegetation is also dependent upon the texture, organic content, pH, Eh, and water saturation level of the dredged material.

168. Metals. Evidence from reclamation of mining tailings suggests that mycorrhizal effects on establishing vegetation in the presence of toxic levels of metals are variable and specific to the metal present. Mycorrhization enhanced tree growth on iron tailings, but mycorrhizae were completely inhibited by copper tailings (Harris and Jurgensen 1977). *Glomus caledonius* was inhibited by manganese (0.014-1.4 mg/ℓ), copper (0.1-1.0 mg/ℓ), and zinc (0.7-7.0 mg/ℓ) (Hepper and Smith 1979, cited by Lambert et al. 1980a). On the other hand, literature confirming the enhancement of vegetation by mycorrhizae on coal spoils is extensive (paragraphs 131-132). Coal spoils are characteristically high in such potentially toxic metals as aluminum, sulfur, manganese, copper, and iron (Marx 1975). Protection from arsenic toxicity in corn by mycorrhizae was demonstrated by Covey et al. (1981).

169. Limited evidence is available that mycorrhizae may function in the detoxification of soils high in certain metal toxicants (Maronek et al. 1981). Heavy metal tolerance mechanisms have been demonstrated in fungi, even in certain mycorrhizal fungi (Ashida 1965). Accumulation and storage of toxic minerals (e.g. sulfur) have been detected in *Pisolithus tinctorius* sporocarps (Muncie et al. 1975, cited by Maronek et al. 1981). Sequestering and storage of heavy metals could be a functional biological transformation system for detoxification (Maronek et al. 1981).

170. Pesticides. Yu et al. (1978) reported higher levels of chlorinated hydrocarbons [i.e. polychlorinated biphenyls (PCB's), analogs and isomers of dichlorodiphenyltrichloroethane (DDT), and dieldrin] in contaminated dredged material disposal sites than in local offsite soil samples. This indicates that the disposal sites studied sometimes retain high levels of these contaminants. After studying the effects of eight pesticides on mycorrhizal barley, maize, and potatoes (*Solanum tuberosum*) in field soils, Ocampo and Hayman (1980) concluded that VAM are affected by fungicides, general biocides, nematicides, and insecticides. They sometimes found effects slight or even positive, but the pesticides usually decreased mycorrhizal infections and spore numbers. Effects of pesticide levels occurring in dredged material disposal sites on mycorrhizae are not known.

Disease

171. Only one instance of disease-induced decline of vegetation planted at dredged material disposal sites was found in the literature (Clairain et al. 1978). However, this example illustrates that plant disease is a potentially limiting factor on the success of revegetation efforts. The most extensive investigations of mycorrhizal-conferred disease resistance have been conducted on pines and horticultural crops (Maronek et al. 1981) (paragraphs 124-126). These studies indicate that mycorrhizal plants are more disease resistant than nonmycorrhizal plants. Several mechanisms proposed to explain resistance are: (a) protection of roots by a well-formed mantle of mycorrhizal fungi; (b) selective pressure on the rhizosphere microflora exerted by host/fungus interactions; (c) utilization of surplus carbohydrates in the roots by mycorrhizal fungi, thereby reducing attraction of pathogens; and (d) inhibition by mycorrhizal secretions of antibiotics and other chemical inhibitors. Similar mechanisms for host resistance may well have evolved for other plant species in addition to pines and horticultural crops. Disease resistance may provide an additional advantage incidental to those for which more extensive documentation is available in the literature.

PART VI: CONCLUSIONS AND RECOMMENDATIONS

Conclusions

172. Mycorrhizal fungi offer significant potential for enhancing establishment of vegetation on dredged material disposal sites. Specific conditions under which mycorrhizae are likely to exert the greatest positive influence occur in upland disposal sites where:

- a. Dredged material is sandy and nutrient-deficient.
- b. Rapid substrate stabilization is imperative.
- c. Essential plant nutrients are present but often soil-bound.

173. Potentially enhancing effects can also be expected on upland sites that are subjected to:

- a. Moisture stress.
- b. Extremes in pH.
- c. Presence of toxins that inhibit plant growth.
- d. High risk of plant disease.
- e. Marginally high salinity.

174. Although occurrence of mycorrhizae on many marsh plants and a few aquatic plants has been demonstrated and enhancement of plant growth has been observed in marsh species, application of mycorrhizae to development of marsh or aquatic vegetation on dredged material disposal sites will not be practical until more is known about the mycorrhizal status of these plants.

Recommendations

175. To evaluate the efficacy of mycorrhizae in the enhancement of establishing vegetation on dredged material disposal sites, the following studies are recommended:

- a. A greenhouse/laboratory study designed to compare mycorrhizal and nonmycorrhizal plant species grown in dredged material samples collected from various disposal sites. Plant height, growth rate, vigor, and seed production (when appropriate) should be used to determine plant success. Total aboveground plant yield should also be used to determine plant success.
- b. A greenhouse study to determine the most efficacious mycorrhizal (fungus/plant) combinations for revegetation of specific dredged material types.

c. A small-scale field study to determine feasibility and efficacy of mycorrhizal plants on dredged material disposal sites.

176. If the above studies establish the efficacy of mycorrhization for enhancing the establishment of vegetation on dredged material disposal sites, techniques for rapid dissemination of the fungi should be developed and field tested on a large scale. Success of these efforts could lead to routine applications of mycorrhizal fungi as part of standard revegetation efforts on dredged material substrates.

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APPENDIX A: TABLES

Explanation of Tables

1. The following three tables of plants that have been found to exhibit mycorrhizae are not offered as a comprehensive list. Data for the tables were drawn only from the References of this literature survey. Therefore, they represent plant/mycorrhizal fungus associations from areas of research having relevance to the subject of this paper. The tables are restricted to the scope of this literature review, which deals primarily with beneficial uses of mycorrhizae in reforestation, land reclamation, and agriculture. The articles in the References include some of international origin; therefore, some plant species from foreign countries are included.

2. Table A1 lists trees, shrubs, and woody vines. Table A2 lists herbaceous plants, including moss, ferns, and cacti. Table A3 lists grasses, sedges, and rushes.

Table A1

Trees, Shrubs, and Woody Vines Exhibiting Mycorrhizae

Plant Scientific Name	Plant Common Name	Fungus Scientific Name	References
Abies	Fir	Nonspecific	Kormanik et al. (1977b); Kuhns (1980); Malloch and Malloch (1981)
A. amabilis	Pacific silver fir	Nonspecific	Vogt et al. (1980)
A. balsamea	Balsam fir	Nonspecific	Malloch and Malloch (1981)
A. concolor	White fir	Nonspecific	Alvarez, Rowney, and Cobb (1979)
A. procera	Noble fir	*Amanita muscaria*	Molina and Trappe (1982)
		Boletus edulis	Molina and Trappe (1982)
		Laccaria laccata	Molina and Trappe (1982)
		Lactarius deliciosus	Marx (1977d); Molina and Trappe (1982)
		Pisolithus tinctorius	Molina and Trappe (1982)
		Rhizopogon cokeri	
		R. occidentalis	
		Suillus brevipes	
		S. lakei	
		Truncocolumella citrina	
*Acacia**	Acacia	Nonspecific	Malloch et al. (1980)
A. arabica		Nonspecific	Khan (1974)
A. greggii		*Glomus epigaeum*	Bethlenfalvay et al. (1984)
		G. intraradices	
		G. mosseae	
		Glomus sp.	

(Continued)

* All genera and species followed by an asterisk in this table were listed by Landin (1978) as "Selected Upland Plant Species for Habitat Development on Dredged Material Sites." When only the genus exhibits an asterisk, Landin has listed a different species from the one (if any) cited here.

Table A1 (Continued)

Plant Scientific Name	Plant Common Name	Fungus Scientific Name	References
A. farnesiana		Nonspecific	Meador (1977)
A. senegal		*Endogone* sp.	Khan (1974)
Acer	Maple	Nonspecific	Kuhns (1980); Malloch et al. (1980); Shuffstall and Medve (1979)
A. negundo	Boxelder	*Glomus mosseae*	Schultz et al. (1981)
		G. etunicatus	Schultz et al. (1981)
*A. rubrum**	Red maple	*Gigaspora gigantea*	Daft and Hacskaylo (1977); Kiernan et al. (1983)
		Glomus aggregatum	Kiernan et al. (1983)
		G. macrocarpus var. *geosporus*	Daft and Hacskaylo (1977)
			Daft and Hacskaylo (1977)
		G. mosseae	Schultz et al. (1981)
		G. etunicatus	Schultz, et al. (1981)
*A. saccharum**	Sugar maple	Nonspecific	Spitko and Tattar (1978)
		G. etunicatus	Schultz et al. (1981)
		G. mosseae	Schultz et al. (1981)
*Aesculus**	Horse-chestnut, buckeye	Nonspecific	Kuhns (1980)
Afzelia	Afzelia	Nonspecific	Malloch et al. (1980)
Aldina	Aldina	Nonspecific	Malloch et al. (1980)
Alnus	Alder	Nonspecific	Kuhns (1980)
A. glutinosa	European alder	Nonspecific	Shuffstall and Medve (1979)
		Alpova diplophloeus	Molina (1981)
		Astraeus pteridis	Molina (1981)
		Paxillus involutus	Molina (1981)
*A. rubra**	Red alder	*Alpova diplophoeus*	Molina and Trappe (1982)
		Zelleromyces gilkeyae	Molina and Trappe (1982)

(Continued)

Table A1 (Continued)

Plant Scientific Name	Plant Common Name	Fungus Scientific Name	References
A. rugosa (=*A. incana*)	Smooth alder, grey alder, speckled alder	Nonspecific	Malloch and Malloch (1981)
		Alpova diplophloeus	Molina (1981)
		Astraeus pteridis	
		Paxillus involutus	
*A. sinuata**	Sitka alder	*Alpova diplophloeus*	
		Astraeus pteridis	
		Paxillus involutus	
A. rhombifolia	White alder	*Alpova diplophloeus*	
		Astraeus pteridis	
		Paxillus involutus	
A. crispa	Green alder, mountain alder	Nonspecific	Malloch and Malloch (1982)
*Amelanchier**	Serviceberry	Nonspecific	Kuhns (1980)
A. sanguinea	Serviceberry	Nonspecific	Malloch and Malloch (1982)
Anthonontha	Anthonontha	Nonspecific	Malloch et al. (1980)
Anthyllis vulneraria	Lady's-fingers	Nonspecific	Read et al. (1976)
Aralia			
A. nudicaulis	Wild sarsaparilla, salsepareille	Nonspecific	Malloch and Malloch (1981)
A. spinosa	Hercules' club	Nonspecific	Shuffstall and Medve (1979)
Araucaria			
A. cunninghami	Hoop pine	*Endogone araucareae*	Bevege et al. (1975)
		E. macrocarpa	Bevege et al. (1975)
		E. mosseae	Bevege et al. (1975)
A. excelsa	Norfolk island pine	*Glomus epigaeus*	Carling and Brown (1980)

(Continued)

Table A1 (Continued)

Plant Scientific Name	Plant Common Name	Fungus Scientific Name	References
Arbutus			
A. menziesii	Madrona	Nonspecific	Largent et al. (1980)
		Cenococcum geophilum	Largent et al. (1980)
		Leccinum manzanitae	Molina and Trappe (1982)
A. unedo	Strawberry tree	Nonspecific	Read (1983)
Ardisia escallonioides	Marlberry	Nonspecific	Meador (1977)
Arctostaphylos	Bearberry		
A. canescens		Nonspecific	Largent et al. (1980)
		Cenococcum geophilum	
A. columbiana		Nonspecific	
		C. geophilum	
		Leccinum manzanitae	Molina and Trappe (1982)
A. glandulosa		Nonspecific	Largent et al. (1980)
A. intricata		Nonspecific	
		C. geophilum	
A. manzanita		Nonspecific	
		C. geophilum	
A. nevadadensis		Nonspecific	
		C. geophilum	
A. nummularia		Nonspecific	
A. patula		Nonspecific	
		C. geophilum	
*A. uva-ursa**	Common bearberry	Nonspecific	Largent et al. (1980); Read (1983); Scannerini and Bonfante-Fasolo (1983)
		Leccinum manzanitae	Molina and Trappe (1982)

(Continued)

Table A1 (Continued)

Plant Scientific Name	Plant Common Name	Fungus Scientific Name	References
*A. uva-ursa** (cont'd)		*Scleroderma hypogaeum*	Molina and Trappe (1982)
		Tricholoma flavovirens	Molina and Trappe (1982)
A. viscida		Nonspecific	Largent et al. (1980)
		C. geophilum	Largent et al. (1980)
Artemisia	Wormwood		
A. nova		Nonspecific	Call (1981); Call and McKell (1982)
A. tridentata		Nonspecific	Call (1981); Call and McKell (1982)
*Atriplex**	Orach		
*A. canescens**	Fourwing saltbush	Nonspecific	Call (1981); Call and McKell (1982)
		Glomus fasciculatus	Lindsey et al. (1977)
		G. mosseae	Lindsey et al. (1977)
A. confertifolia		Nonspecific	Call (1981); Call and McKell (1982)
A. cunnata		Nonspecific	Call (1981); Call and McKell (1982)
A. polycarpa		*Glomus* sp.	Bethlenfalvay et al. (1984)
*Baccharis halimifolia** var. *angustior*	Groundsel	Nonspecific	Meador (1977)
Bauhinia		Nonspecific	Malloch et al. (1980)
Betula	Birch	Nonspecific	Kuhns (1980); Marx (1977d)
B. alleghaniensis	Yellow birch	*Pisolithus tinctorius*	Maronek and Hendrix (1980)
B. lenta	Cherry birch	Nonspecific	Marx (1975)
		P. tinctorius	Marx (1976), (1977d)
*B. nigra**	River birch	*P. tinctorius*	Marx (1977d)
B. papyrifera	Paper birch	Nonspecific	Malloch and Malloch (1981)
B. pendula	Common silver birch, European white birch	Nonspecific	Shuffstall and Medve (1979)
		Laccaria laccata	Ford et al. (1980)

(Continued)

Table A1 (Continued)

Plant Scientific Name	Plant Common Name	Fungus Scientific Name	References
B. pendula (cont'd)		*Lactarius pubescens*	Ford et al. (1980)
		Paxilla involutus	Molina and Trappe (1982)
		Pisolithus tinctorius	Marx (1975), (1976), (1977d); Molina and Trappe (1982)
		Hebeloma spp.	Ford et al. (1980)
B. populifolia	White birch	Nonspecific	Marx (1975)
		Pisolithus tinctorius	Marx (1976), (1977d)
B. pumila	Swamp birch	Nonspecific	Malloch and Malloch (1982)
Bursera simaruba	Torchwood	Nonspecific	Meador (1977)
Calluna	Heather	Nonspecific	Largent et al. (1980); Malloch et al. (1980)
C. vulgaris	Common heather	Nonspecific	Bradley et al. (1982); Read (1983); Scannerini and Bonfante-Fasolo (1983)
Carica papaya	Papaya	Nonspecific	Hayman (1980); Janos (1980a)
		Gigaspora heterogama	Schenck and Kellum (1978)
		G. margarita	Schenck and Kellum (1978)
		Glomus macrocarpus var. *macrocarpus*	Schenck and Kellum (1978)
*Carpinus**	Hornbeam, ironwood	Nonspecific	Kuhns (1980)
*Carya**	Hickory	Nonspecific	Kormanik et al. (1977b); Malloch et al. (1980)
*C. illinoensis**	Pecan	*Pisolithus tinctorius*	Marx (1977d)
Cassiope mertensiana		Nonspecific	Largent et al. (1980)
Ceanothus	Redroot		
C. prostratus		*Acaulospora trappei*	Kormanik et al. (1977b)
C. velutinus		*A. trappei*	Biermann (1983)
Cedrus	Cedrus	Nonspecific	Kuhns (1980)
*Celtis**	Hackberry	Nonspecific	Kuhns (1980)

(Continued)

Table A1 (Continued)

Plant Scientific Name	Plant Common Name	Fungus Scientific Name	References
Cercidiphyllum sp.	Katsura	Nonspecific	Kuhns (1980)
Cercocarpus montanus		*Glomus* sp.	Williams (1979)
Cercis canadensis	Redbud	Nonspecific	Maronek et al. (1981)
		G. aggregatum	Kiernan et al. (1983)
		G. caledonius	Kiernan et al. (1983)
		G. fasciculatus	Kiernan et al. (1983)
Chamaedaphne calyculata	Leather-leaf	Nonspecific	Malloch and Malloch (1982)
Chilopsis linearis		*G. mosseae*	Bethlenfalvay et al. (1984)
		Glomus sp.	Bethlenfalvay et al. (1984)
Chimaphila	Wintergreen		
C. menziesii		Nonspecific	Largent et al. (1980)
C. umbellata		Nonspecific	Largent et al. (1980)
Chrysothamnus nauseosus	Rubber rabbitbrush	Nonspecific	Call (1981); Call and McKell (1982)
		Glomus fasciculatus	Lindsey et al. (1977)
		G. mosseae	Lindsey et al. (1977)
Cistus salvifolius	Rock rose	*Hebeloma sacchariolens*	Rosell (1981)
Citrus	Citrus	Nonspecific	Hayman (1980)
		Gigaspora gregaria	Nicolson and Schenck (1979)
		G. margarita	Nemec et al. (1981); Nicolson and Schenck (1979)
		Glomus constrictus	Nemec et al. (1981)
		G. etunicatus	McGraw and Schenck (1981); Nemec (1983); Nemec et al. (1981); Nicolson and Schenck (1979)
		G. fasciculatus	Nemec et al. (1981); Nicolson and Schenck (1979)
		G. macrocarpus	
		G. microcarpus	
		G. monosporus	

(Continued)

Table A1 (Continued)

Plant Scientific Name	Plant Common Name	Fungus Scientific Name	References
Citrus (cont'd)		*G. mosseae*	Marx (1975); Nemec et al. (1981); Nemec (1983)
		Sclerocystis sinuosa	Nemec et al. (1981); Nicolson and Schenck (1979)
C. amblicarpa	Brazilian sour orange	Nonspecific	Menge (1983); Menge et al. (1977); Mehraveran (1977)
		Glomus fasciculatus	
C. aurantium	Sour orange, keen sour orange	Nonspecific	Menge et al. (1977); Ratnayake et al. (1978)
		Gigaspora margarita	Schenck and Kellum (1978)
		Glomus epigaeus	McGraw and Schenck (1980)
		G. etunicatus	McGraw and Schenck (1980)
		G. fasciculatus	Mehraveran (1977); Timmer and Leyden (1979)
		G. macrocarpus	McGraw and Schenck (1980); Schenck and Kellum (1978)
		G. microcarpus	McGraw and Schenck (1980)
		G. mosseae	Krikun and Levy (1980); McGraw and Schenck (1980)
C. jambhiri	Rough lemon	Nonspecific	Levy and Krikun (1980); Menge et al. (1977)
		Glomus fasciculatus	Mehraveran (1977)
		G. mosseae	Krikun and Levy (1980)
C. macrophyla	Alemow	Nonspecific	Menge et al. (1977)
		Glomus fasciculatus	Mehraveran (1977)
C. reticulata	Cleopatra mandarin	*G. fasciculatus*	Manjunath et al. (1983)
		G. mosseae	Krikun and Levy (1980)
C. sinensis	Sweet orange	*G. fasciculatus*	Johnson et al. (1982b); Schenck and Kellum (1978)
Citrus sinensis X *Poncirus trifoliata*	Carrizo citrange	*Gigaspora margarita*	Schenck and Kellum (1978)
		Glomus fasciculatus	Mehraveran (1977)
		G. macrocarpus	Schenck and Kellum (1978)

(Continued)

Table A1 (Continued)

Plant Scientific Name	Plant Common Name	Fungus Scientific Name	References
C. trifoliata	Trifolate orange	*G. fasciculatus*	Mehraveran (1977)
Coccoloba	Sea grape	Nonspecific	Malloch et al. (1980)
C. diversifolia	Tie tongue	Nonspecific	Meador (1977)
Coffea	Coffee	Nonspecific	Hayman (1980); Rao and Parvathi (1982)
Comptonia peregrina	Sweetfern	Nonspecific	Malloch and Malloch (1981)
*Cornus**	Dogwood, Cornell		
*C. amomum**	Red willow, silky dogwood	Nonspecific	Barnhill (1981)
C. canadensis	Dwarf cornel	Nonspecific	Malloch and Malloch (1981)
*C. florida**	Flowering dogwood	Nonspecific	Barnhill (1981); Shuffstall and Medve (1979)
		Glomus aggregatum	Kiernan et al. (1983)
C. stolonifera	Red-osier dogwood	Nonspecific	Molina (1981); Barnhill (1981)
Corylus	Hazel	Nonspecific	Kuhns (1980)
C. avellana	Cobnut	*Paxillus involutus*	Molina and Trappe (1982)
		Tuber macrosporum	Scannerini and Bonfante-Fasolo (1983)
C. cornuta	Beaked hazel	Nonspecific	Malloch and Malloch (1982)
*Crataegus**	Hawthorne	Nonspecific	Shuffstall and Medve (1979)
Cupressus	Cypress	Nonspecific	Malloch et al. (1980)
Diervilla lonicera	Bush honeysuckle	Nonspecific	Malloch and Malloch (1981)
Dipholis salicifolia	Bustic	Nonspecific	Meador (1977)
Diptychandra		Nonspecific	Malloch et al. (1980)
Dodonaea viscosa	Varnish leaf	*Endogone* sp.	Khan (1974)
*Elaegnus**		Nonspecific	Malloch et al. (1980)
*E. umbellata**	Autumn olive	Nonspecific	Shuffstall and Medve (1979)

(Continued)

Table A1 (Continued)

Plant Scientific Name	Plant Common Name	Fungus Scientific Name	References
E. umbellata (cont'd)		*Acaulospora bireticulata*	Kiernan et al. (1983)
		A. elegans	
		Glomus constrictus	
		G. macrocarpus var. *geosporus*	
Eperua		Nonspecific	Malloch et al. (1980)
Ephedra	Mormontea		
E. californica		*Glomus fasciculatum*	Bethlenfalvay et al. (1984)
		G. mosseae	
		G. fasciculatum	
		G. mosseae	
Epigaea repens	Trailing arbutus, may flower	Nonspecific	Malloch and Malloch (1981)
Erica	Heath		
E. bauera	Cape heath	Nonspecific	Read (1983)
Eucalyptus	Eucalyptus	Nonspecific	Malloch et al. (1980)
		Cenococcum geophilum	Malajezuk et al. (1982)
		C. graniforme	Pope (1980)
		Boletus portentosus	Malajezuk et al. (1982)
		Cortinarius archeri	
		C. microarcheri	
		Hydnangium carneum	
		Hymenogaster albus	
		Hysterangium incarceratum	
		Lycoperdon gemmatum	

(Continued)

Table A1 (Continued)

Plant Scientific Name	Plant Common Name	Fungus Scientific Name	References
Eucalyptus (cont'd)		*Pisolithus tinctorius*	Malajezuk et al. (1982); Marx (1977d)
		Scleroderma albidum	Malajezuk et al. (1982)
		S. bovista	
		S. cepa	
E. archeri		*Hydnangium carneum*	
		Hymenogaster albellus	
		Scleroderma albidum	
E. bridgesiana		*Pisolithus tinctorius*	Malajezuk et al. (1982); Marx (1977d)
E. calophylla		*Ramaria sinapicolor*	Malajezuk et al. (1982)
E. camphora		*Cenococcum graniforme*	Rose (1980a)
		Pisolithus tinctorius	Rose (1980a)
		Scleroderma geaster	Rose (1980a)
E. camuldulensis	River red gum	*Cenococcum geophilum*	Malajezuk et al. (1982)
		Pisolithus tinctorius	Malajezuk et al. (1982); Marx (1977d)
		Scleroderma verrucosum	Malajezuk et al. (1982)
E. citriodora	Lemon-scented gum	*Scleroderma verrucosum*	Malajezuk et al. (1982)
E. dalrympleana		*Hydnangium carneum*	Malajezuk et al. (1982)
		Pisolithus tinctorius	Malajezuk et al. (1982); Marx (1977d)
E. deglupta		*Scleroderma verrucosum*	Malajezuk et al. (1982)
E. dives		*Octaviania densa*	
		Scleroderma cepa	
E. erythrocorys		*Lycoperdon gemmatum*	
		Tricholoma pardinum	
E. fastigiata		*Octaviania densa*	
		Pisolithus tinctorius	Malajezuk et al. (1982); Marx (1977d)

(Continued)

Table A1 (Continued)

Plant Scientific Name	Plant Common Name	Fungus Scientific Name	References
E. forrestiana		*Lycoperdon gemmatum*	Malajezuk et al. (1982)
		Tricholoma pardinum	
E. gigantea		*Cenococcum geophilum*	
		Hydnangium carneum	
E. glaucescens		*Hydnangium carneum*	
E. globulus	Blue gum	*Cenococcum geophilum*	
		Hydnangium carneum	
		Hymenogaster albellus	
		H. albus	
		Hysterangium incarceratum	
E. gomphocephala		*Scleroderma verrucosum*	
E. grandis		*Cenococcum geophilum*	
		Macrolepiota procera	
		Octaviania densa	
		Pisolithus tinctorius	Malajezuk et al. (1982); Marx (1977d)
		Scleroderma verrucosum	Malajezuk et al. (1982)
		Tricholoma pardinum	Malajezuk et al. (1982)
E. gummifera		*Pisolithus tinctorius*	Malajezuk et al. (1982); Marx (1977d)
E. gunnii		*Hydrangium carneum*	Malajezuk et al. (1982)
E. kirtoniana		*Scleroderma verrucosum*	Malajezuk et al. (1982)
E. laevopinea		*Cenococcum graniforme*	Rose (1980a)
		Pisolithus tinctorius	Rose (1980a)
		Scleroderma geaster	Rose (1980a)
E. leucoxylon		*Pisolithus tinctorius*	Malajezuk et al. (1982); Marx (1977d)

(Continued)

Table A1 (Continued)

Plant Scientific Name	Plant Common Name	Fungus Scientific Name	References
E. macrorrhyncha		*Scleroderma cepa* (=*S. flavidum*)	Malajezuk et al. (1982)
E. maculata		*Pisolithus tinctorius*	Malajezuk et al. (1982); Marx (1977d)
E. macarthurii		*Cenoccoccum graniforme*	Rose (1980a)
		Pisolithus tinctorius	Rose (1980a)
		Scleroderma geaster	Rose (1980a)
E. marginata		*Cenococcum geophilum*	Malajezuk and Hingston (1981); Malajezuk et al. (1982)
		Ramaria sinapicolor	Malajezuk et al. (1982)
E. microcorys		*Pisolithus tinctorius*	Malajezuk et al. (1982); Marx (1977d)
E. niphophylla	Snow gum	*Hydnangium carneum*	Malajezuk et al. (1982)
		Hymenogaster albellus	Malajezuk et al. (1982)
E. nitens		*Hydnangium carneum*	Malajezuk et al. (1982)
E. nova-anglica		*Cenoccoccum graniforme*	Rose (1980a)
		Pisolithus tinctorius	Rose (1980a)
		Scleroderma geaster	Rose (1980a)
E. odorata		*Scleroderma verrucosum*	Malajezuk et al. (1982)
E. paniculata		*Scleroderma verrucosum*	
E. pauciflora		*Scleroderma cepa* (=*S. flavidum*)	
E. perriniana	Spinning gum	*Hydnangium carneum*	
		Hymenogaster albellus	
		H. albus	
E. pilularis		*Octaviania densa*	
E. polyanthemos		*Pisolithus tinctorius*	Malajezuk et al. (1982); Marx (1977d)
E. pulverulenta		*Hydnangium carneum*	Malajezuk et al. (1982)
		Hymenogaster albellus	Malajezuk et al. (1982)

(Continued)

Table A1 (Continued)

Plant Scientific Name	Plant Common Name	Fungus Scientific Name	References
E. punctata		*Scleroderma verrucosum*	Malajezuk et al. (1982)
E. pyriformis		*Lycoperdon gemmatum*	Malajezuk et al. (1982)
		Tricholoma pardinum	Malajezuk et al. (1982)
E. radiata		*Cenococcum graniforme*	Rose (1980a)
		Pisolithus tinctorius	Malajezuk et al. (1982); Marx (1977d); Rose (1980a)
		Scleroderma geaster	Rose (1980a)
E. regnans		*Agaricus xanthodermus*	Malajezuk et al. (1982)
		Cenococcum geophilum	
		Cortinarius fragilipes	
		C. ochraceus	
		C. purpurascens	
		C. radicatus	
		C. subcinnamomeus	
		Gymnopilus pampeanus	
		Hygrophorus coccineus	
		Hymenogaster violaceus	
		Hysterangium inflatum	
		Mesophellia arenaria	
		Inocybe olivaceofulvus	
		Naematoloma fasciculare	
		Russula purpureoflava	
		Tricholoma coarctatum	
E. robusta		*Octaviania densa*	
		Pisolithus tinctorius	Malajeuzuk et al. (1982); Marx (1977d)
		Scleroderma verrucosum	Malajeuzuk et al. (1982)

(Continued)

Table A1 (Continued)

Plant Scientific Name	Plant Common Name	Fungus Scientific Name	References
E. rossii		*Octaviania densa*	Malajezuk et al. (1982)
E. rudis		*Octaviania densa*	Malajezuk et al. (1982)
		Scleroderma verrucosum	Malajezuk et al. (1982)
E. sieberi		*Pisolithus tinctorius*	Malajezuk et al. (1982); Marx (1977d)
E. st.-johnii		*Pisolithus tinctorius*	Malajezuk et al. (1982); Marx (1977d); Rose (1980a)
		Scleroderma cepa (=*S. flavidum*)	Malajezuk et al. (1982)
E. tereticornis		*Scleroderma verrucosum*	Malajezuk et al. (1982)
E. torelliana		*Scleroderma verrucosum*	Malajezuk et al. (1982)
E. viminalis		*Cenococcum graniforme*	Rose (1980a)
		Octaviania densa	Malajezuk et al. (1982)
		Pisolithus tinctorius	Rose (1980a)
		Scleroderma geaster	Rose (1980a)
Eugenia longipes (=*Myrtus bahamensis*)	Stopper	Nonspecific	Meador (1977)
Eupera		Nonspecific	Largent et al. (1980)
*Fagus**	Beech	Nonspecific	Harley (1981); Harley and McCready (1981); Kormanik et al. (1977b); Kuhns (1980)
		Rhizoctonia sp.	Harley and Waid (1955)
		Trichoderma viride	Harley and Waid (1955)
F. sylvatica	Common beech	Nonspecific	Harley (1978)
Fouquieria splendens	Ocotillo	*Glomus epigaeum*	Bethlenfalvay et al. (1984)
		Glomus sp.	Bethlenfalvay et al. (1984)
Ficus	Fig		
F. citrifolia	Wild banyan tree	Nonspecific	Meador (1977)
F. glabrata		Nonspecific	Janos (1980)

(Continued)

Table A1 (Continued)

Plant Scientific Name	Plant Common Name	Fungus Scientific Name	References
*Fraxinus**	Ash	Nonspecific	Kormanik et al. (1977b); Kuhns (1980)
*F. americana**	White ash	Nonspecific	Kiernan et al. (1983)
		Glomus fasciculatus	Ponder (1984)
F. nigra	Black ash	Nonspecific	Malloch and Malloch (1982)
*F. pennsylvanica**	Green ash	*Glomus etunicatus*	Schultz et al. (1981)
Fuchsia sp.	Fuchsia	Nonspecific	Phillips and Hayman (1970)
*Gaultheria**	Aromatic wintergreen	*Glomus mosseae*	Schultz et al. (1981)
G. hispidula	Creeping snowberry	Nonspecific	Malloch and Malloch (1981)
G. ovatifolia		Nonspecific	Largent et al. (1980)
G. procumbens	Winterberry	Nonspecific	Malloch and Malloch (1981)
G. shallon		Nonspecific	Largent et al. (1980)
		Cenococcum geophilum	Largent et al. (1980)
Gibertiodendron		Nonspecific	Malloch et al. (1980)
Ginkgo	Ginkgo	Nonspecific	Kuhns (1980)
*Gleditsia**	Honey locust	Nonspecific	Kuhns (1980)
Glycoxylon		Nonspecific	Malloch et al. (1980)
Grayia spinosa	Spiny hop sage	Nonspecific	Call (1981); Call and McKell (1982)
Griselinia tittoralis		*Glomus microcarpus*	Powell (1975)
Hedera helix	English ivy	Nonspecific	Hayman (1974); Read et al. (1976)
Hevea	Rubber	Nonspecific	Hayman (1980)
Inga		Nonspecific	Malloch et al. (1980)
Intsia		Nonspecific	Malloch et al. (1980)
Juglans	Walnut	Nonspecific	Kormanik et al. (1977b); Malloch et al. (1980)
*J. nigra**	Black walnut	Nonspecific	Ponder (1979)
		Glomus etunicatus	Schultz et al. (1981)
		G. fasciculatus	Ponder (1984)

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Table A1 (Continued)

Plant Scientific Name	Plant Common Name	Fungus Scientific Name	References
J. nigra (cont'd)		*G. mosseae*	Schultz et al. (1981)
Julbernardia		Nonspecific	Malloch et al. (1980)
*Juniperus**	Juniper	Nonspecific	Malloch et al. (1980)
J. californicus		*Glomus epigaeum*	Bethlenfalvay et al. (1984)
		G. mossease	Bethlenfalvay et al. (1984)
Kalmia	Laurel		
K. angustifolia	Lambkill, sheepkill	Nonspecific	Malloch and Malloch (1981)
K. polifolia	Pale laurel	Nonspecific	Largent et al. (1980)
Larix	Larch	Nonspecific	Kormanik et al. (1977b); Kuhns (1980)
		Cenococcum geophilum	Danielson (1982)
L. laricina	Eastern larch	*Complexipes moniliformis*	Danielson (1982)
L. occidentalis	Western larch	*Fuscoboletinus alruginascens*	Molina and Trappe (1982)
Larrea divaricata	Creosote bush	*Glomus mosseae*	Bethlenfalvay et al. (1984)
		Glomus sp.	Bethlenfalvay et al. (1984)
Ledum	Labrador tea		
L. glandulosum var. *californica*		Nonspecific	Largent et al. (1980)
L. glandulosum var. *glandulosum*		Nonspecific	Largent et al. (1980)
		Cenococcum geophilum	Largent et al. (1980)
L. groenlandicum		Nonspecific	Malloch and Malloch (1981)
Leiophyllum	Sand myrtle	Nonspecific	Largent et al. (1980)
Leucaena leucocephala	Lead tree	Nonspecific	Yost and Fox (1979)
Leucothoe daviseae	Fetter-brush	Nonspecific	Read (1983); Scannerini and Bonfante-Fasolo (1983)
		Cenococcum geophilum	Largent et al. (1980)

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Table A1 (Continued)

Plant Scientific Name	Plant Common Name	Fungus Scientific Name	References
*Liquidambar styraciflua**	Sweetgum	Nonspecific	Hayman (1980); Kormanik et al. (1977b); Maronek et al. (1981); Phillips and Hayman (1970)
		Gigaspora sp.	Brown et al. (1981); Kormanik et al. (1981)
		Glomus aggregatum	Kiernan et al. (1983)
		G. constricta	Kiernan et al. (1983)
		G. etunicatus	Brown et al. (1981); Kiernan et al. (1983); Kormanik et al. (1981); Schultz et al. (1979)
		G. fasciculatus	Brown et al. (1981); Kiernan et al. (1983); Kormanik et al. (1981)
		G. macrocarpus var. *geosporus*	Kiernan et al. (1983)
		G. macrocarpus var. *macrocarpus*	Kiernan et al. (1983)
		G. microcarpus	Kiernan et al. (1983)
		G. mosseae	Brown et al. (1981); Kormanik et al. (1977a); Kormanik et al. (1981); Marx (1975); Schultz et al. (1979)
Liriodendron	Poplar	Nonspecific	Barnhill (1981); Kormanik et al. (1977b); Kuhns (1980)
*L. tulipifera**	Yellow poplar	Nonspecific	Scannerini and Bonfante-Fasolo (1983)
		Endogone sp.	Gerdemann (1974)
		Glomus caledonius	Kiernan et al. (1983)
		G. fasciculatus	Maronek et al. (1981)
		G. microcarpus	Kiernan et al. (1983)
Lonicera canadensis	Fly-honeysuckle	Nonspecific	Malloch and Malloch (1982)
Lysiloma latisiliqua	Wild tamarind	Nonspecific	Meador (1977)
Macrolobium		Nonspecific	Malloch et al. (1980)
*Malus**	Apple	Nonspecific	Kuhns (1980)

(Continued)

Table A1 (Continued)

Plant Scientific Name	Plant Common Name	Fungus Scientific Name	References
M. domestica	Orchard apple	*Glomus mosseae*	Covey et al. (1981); Strobel et al. (1982)
		Pisolithus tinctorius	Green et al. (1982)
*M. pumila**	Apple	*Glomus epigaeum*	Graw (1979); Jasper et al. (1979)
M. seiboldi		Nonspecific	Barnhill (1981)
M. sylvestris	Common crab apple	*Gigaspora calospora*	Trappe et al. (1973)
		Glomus caledonius	
		G. fasciculatus	
		G. macrocarpus var. *geosporus*	
Magnolia grandiflora*	Southern magnolia	*G. fasciculatus*	Maronek et al. (1981)
Mastchodentron foetidissium	Mastic	Nonspecific	Meador (1977)
Menziesia	Minnie-bush	Nonspecific	Largent et al. (1980)
Metropium toxiferum	Poisonwood	Nonspecific	Meador (1977)
Monopetalanthus		Nonspecific	Meador (1977)
*Myrica**			
*M. cerifera**	Wax myrtle	Nonspecific	Meador (1977)
M. pennsylvanica	Bayberry	*Acaulospora scobiculata*	Koske (1981)
		Gigaspora calospora	
		G. gigantea	
		Glomus etunicatus	
		G. fasciculatus	
Myrsine guianensis	Myrsine	Nonspecific	Meador (1977)
Nectandra coriacea	Lancewood	Nonspecific	Meador (1977)
Neea		Nonspecific	Malloch et al. (1980)
Nothofagus	Beech	Nonspecific	Malloch et al. (1980)

(Continued)

Table A1 (Continued)

Plant Scientific Name	Plant Common Name	Fungus Scientific Name	References
*Nyssa sylvatica**	Black gum	*Glomus mosseae*	Keeley (1980)
Olea europaea	Olive	*G. constrictus*	Daniels and Menge (1981)
		G. epigaeus	
		G. fasciculatus	
		G. mosseae	
*Ostrya**	Hop-hornbeam, ironwood	Nonspecific	Kuhns (1980)
Paramacrolobium		Nonspecific	Malloch et al. (1980)
Parthenocissus quinquefolia	Virginia creeper	Nonspecific	Meador (1977)
Pernettya		Nonspecific	Read (1983)
Persea			
P. americana	Avocado	Nonspecific	Maronek et al. (1981); Schenck and Kellam (1978)
		Glomus fasciculatus	Menge et al. (1980)
*P. borbonia**	Red bay	Nonspecific	Meador (1977)
Phyllodoce empetriformis		Nonspecific	Largent et al. (1980)
Picea	Spruce	Nonspecific	Kuhns (1980); Malloch et al. (1980)
P. abies	Norway spruce	*Pisolithus tinctorius*	Maronek and Hendrix (1980)
P. engelmanni	Englemann spruce	Nonspecific	Oswald and Ferchau (1968)
P. glauca	White spruce	Nonspecific	Danielson (1982); Malloch and Malloch (1982)
P. mariana	Black spruce	Nonspecific	Malloch and Malloch (1981)
P. pungens	Colorado spruce	Nonspecific	Chambers et al. (1980a)
P. sitchensis	Sitka spruce	*Pisolithus tinctorius*	Genua et al. (1982)
		Amanita muscaria	Molina and Trappe (1982)
		Boletus edulis	
		Laccaria laccata	
		Lactarius deliciosus	

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Table A1 (Continued)

Plant Scientific Name	Plant Common Name	Fungus Scientific Name	References
P. sitchensis (cont'd)		*L. rufus*	Alexander (1981)
		Rhizopogon fuscorubens	Molina and Trappe (1982)
Pinus	Pine	Nonspecific	Kormanik et al. (1977b); Kuhns (1980); Malloch et al. (1980)
		Pisolithus tinctorius	Peeler and Mullins (1982)
P. albicaulis	Whitebark pine	*Gastroboletus subalpinus*	Molina and Trappe (1982)
P. aristata	Bristle-cone pine	Nonspecific	Oswald and Ferchau (1968)
P. ayacahuite	Mexican white pine	*Pisolithus tinctorius*	Marx (1977d)
P. banksiana	Jack pine	Nonspecific	Danielson (1982); Malloch and Malloch (1981); Marx (1980)
		Amanita muscaria	Molina and Trappe (1982)
		Boletus edulis	Molina and Trappe (1982)
		Laccaria laccata	Molina and Trappe (1982)
		Pisolithus tinctorius	Marx (1976), (1977d); Marx et al. (1982)
*P. caribaea** (=*P. elliottii*)	Slash pine	Nonspecific	Marx (1975)
		Cenoccoccum graniforme	Haiskaylo and Vozzo (1967)
		Corticium bicolor	Haiskaylo and Vozzo (1967)
		Pisolithus tinctorius	Marx (1976), (1977d); Marx et al. (1977), (1982)
		Rhizopogon roseolus	Haiskaylo and Vozzo (1967)
		Suillus cothurnatus	Haiskaylo and Vozzo (1967)
		Thelephora terrestris	Marx et al. (1977)
P. caribaea var. *bahamensis*		*Pisolithus tinctorius*	Marx (1977d)
P. caribaea var. *caribaea*		*P. tinctorius*	Marx (1977d)

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Table A1 (Continued)

Plant Scientific Name	Plant Common Name	Fungus Scientific Name	References
P. caribaea var. *elliottii*		*P. tinctorius*	Marx (1977d)
P. caribaea var. *hondurensis*		Nonspecific	Hart et al. (1980)
		Pisolithus tinctorius	Marx (1977d)
P. cembra	Arolla pine	*P. tinctorius*	Marx (1977d)
*P. clausa**	Sand pine	Nonspecific	Marx (1975)
		P. tinctorius	Marx (1976), (1977d)
P. clausa var. *clausa*		*P. tinctorius*	Marx (1977d)
P. clausa var. *immuginata*		*P. tinctorius*	Marx (1977d); Marx et al. (1977); Ruehl and Brendemuehl (1981); Schenck (1981)
		Thelephora terrestris	Marx et al. (1977)
*P. contorta**	Lodgepole pine, Shore pine	*Lactarius deliciosus*	Molina and Trappe (1982)
		Leccinum manzanitae	Molina and Trappe (1982)
		Paxillus involutus	Molina and Trappe (1982)
		Pisolithus tinctorius	Cline and Reid (1982); France and Reid (1983); Maronek et al. (1981); Marx (1977d)
		Rhizopogon cokeri	Molina and Trappe (1982)
		R. fuscorubens	Molina and Trappe (1982)
		R. luteolus	Cline and Reid (1982)
		R. occidentalis	Molina and Trappe (1982)
		Scleroderma hypogaeum	Molina and Trappe (1982)
		Suillus brevipes	Molina and Trappe (1982)
		S. granulatus	Cline and Reid (1982)
		Tricholoma flavovirens	Molina and Trappe (1982)
P. densiflora	Japanese red pine	Nonspecific	Lee (1981)
		Pisolithus tinctorius	Marx (1977d)

(Continued)

Table A1 (Continued)

Plant Scientific Name	Plant Common Name	Fungus Scientific Name	References
P. echinata	Shortleaf pine	Nonspecific	Berry (1979b); Marx (1975)
		Laccaria laccata	Marx and Davey (1969a)
		Leucopaxillus cerealis var. *piceina*	Marx and Davey (1969a)
		Pisolithus tinctorius	Berry and Marx (1976); Dixon et al. (1979); Marx (1970), (1976), (1977d); Marx and Davey (1969a), (1969b); Marx et al. (1982); Ruehl et al. (1981a), (1981b)
		Suillus luteus	Marx and Davey (1969a)
		Thelephora terrestris	Marx (1970a); Ruehl et al. (1981a), (1981b)
P. flexilus	Limber pine	Nonspecific	Oswald and Ferchau (1968)
P. jeffreyi (=*P. ponderosa* var. *jeffreyi*)	Jeffrey pine	*Pisolithus tinctorius*	Marx (1977d)
P. khasya		*P. tinctorius*	Marx (1977d)
P. koraiensis	Korean pine	Nonspecific	Lee (1981)
P. lambertiana	Sugar pine	*Pisolithus tinctorius*	Marx (1977d)
P. leiophylla	Chihuahua pine	*P. tinctorius*	
P. merkusii		*P. tinctorius*	
P. microacana		*P. tinctorius*	
P. monticola	Western white pine	*Amanita muscaria*	Molina and Trappe (1982)
P. montana	Montana pine	*Pisolithus tinctorius*	Marx (1977d)
P. mugo	Dwarf mountain pine	Nonspecific	Ledgard (1976)
		Lactarius rufus	Alexander (1981)
		Pisolithus tinctorius	Marx (1977d)
P. niger	Australian pine	*P. tinctorius*	Maronek and Hendrix (1980); Marx (1977d); Marx et al. (1982)
P. oocarpa		*P. tinctorius*	Marx (1977d)

(Continued)

Table A1 (Continued)

Plant Scientific Name	Plant Common Name	Fungus Scientific Name	References
P. occidentalis		*P. tinctorius*	Marx (1977d)
*P. palustris**	Longleaf pine	*P. tinctorius*	Kais et al. (1981); Marx (1977d); Marx et al. (1982)
P. patula	Jelecote pine	Nonspecific	Marais and Kotze (1978a), (1978b), (1978c)
		P. tinctorius	Marx (1977d)
P. pinaster	Maritime pine	*P. tinctorius*	Marx (1977d)
P. ponderosa	Ponderosa pine	*Boletus edulis*	Molina and Trappe (1982)
		Cortinarius pistorius	Molina and Trappe (1982)
		Hebeloma crustuliniforme	Trappe (1977)
		Hysterangium separabile	Molina and Trappe (1982)
		Laccaria laccata	Molina and Trappe (1982); Trappe (1977)
		Lactarius deliciosus	Molina and Trappe (1982)
		Pisolithus tinctorius	Cline and Reid (1982); Marx et al. (1982); Molina and Trappe (1982); Riffle and Tinus (1982); Trappe (1977)
		Rhizopogon cokeri	Molina and Trappe (1982)
		R. luteolus	Cline and Reid (1982)
		R. occidentalis	Molina and Trappe (1982)
		Suillus granulatus	Cline and Reid (1982)
		Thelephora terrestris	Riffle and Tinus (1982); Trappe (1977)
		Tricholoma flavovirens	Molina and Trappe (1982)
P. pseudostrobus		*Pisolithus tinctorius*	Marx (1977d)
P. radiata	Monterey pine	Nonspecific	Berry (1979b)
		Amanita muscaria	Chu-Chou (1979); Malajezuk et al. (1982)
		A. phalloides	Malajezuk et al. (1982)
		Boletus auriporus	Malajezuk et al. (1982)
		B. piperatus	Malajezuk et al. (1982)

(Continued)

Table A1 (Continued)

Plant Scientific Name	Plant Common Name	Fungus Scientific Name	References
P. radiata (cont'd)		*Cantharella cibarius*	Malajezuk et al. (1982)
		Cenococcum geophilium	
		Chroogomphus rutilus	
		C. vinicolor	
		Endogone flammicorona	
		E. lactiflua	
		Hebeloma crustuliniforme	
		Hysterangium separabile	
		Inocybe lacera	
		Laccaria laccata	
		Lactarius deliciosus	
		Pisolithus tinctorius	Malajezuk et al. (1982); Marx (1970a), (1977d); Marx and Barnett (1974); Marx and Beattie (1977); Marx et al. (1979); Ruehl (1982); Ruehl and Brendemuehl (1981)
		Rhizopogon luteolus	Bevege et al. (1975); Malajezuk et al. (1982); Reid and Bowen (1979); Theodorou (1980)
		R. ochraceorubens	Malajezuk et al. (1982)
		R. roseolus	
		R. rubescens	
		R. subcaerulescens	
		Scleroderma bovista	
		S. citrinum	
		S. verucosum	
		Suillus acerbus	
		S. bovinus	
		S. brevipes	

(Continued)

Table A1 (Continued)

Plant Scientific Name	Plant Common Name	Fungus Scientific Name	References
P. radiata (cont'd)		*S. granulatus*	Malajezuk et al. (1982)
		S. grevillei	
		S. luteus	
		S. pungens	
		S. subacerbus	
		S. subaeureus	
		Thelephora americana	
		T. terrestris	Chu-Chou (1979); Kelley (1979); Lee (1981); Reid and Bowen (1979); Ruehl (1982)
P. resinosa	Red pine	Nonspecific	Marx (1975)
		Pisolithus tinctorius	Marx (1976), (1977d); Sohn (1981); Yang and Wilcox (1984)
		Suillus subluteus	Yang and Wilcox (1984)
P. rigida	Pitch pine	Nonspecific	Lee (1981); Marx (1975), (1976)
		Pisolithus tinctorius	Marx (1977d), (1980)
P. rigida var. *taeda*		Nonspecific	Lee (1981)
P. rudis		*P. tinctorius*	Marx (1977d)
P. serotina	Pond pine, pocosin pine	*P. tinctorius*	Marx (1977d)
*P. strobus**	Eastern white pine	Nonspecific	Marx (1975)
		Cenococcum geophilum	Piché and Fortin (1982)
		Hebeloma cylindrosporum	Piché and Fortin (1982)
		Paxillus involutus	Piché and Fortin (1982)
		Pisolithus tinctorius	Marx (1976), (1977d); Marx et al. (1977); Piché and Fortin (1982); Piché (1983)
		Suillus granulatus	Piché and Fortin (1982)
		S. tomentosus	Piché and Fortin (1982)
		Thelephora terrestris	Marx et al. (1977); Piché and Fortin (1982)

(Continued)

Table A1 (Continued)

Plant Scientific Name	Plant Common Name	Fungus Scientific Name	References
P. sylvestris	Scots pine	*Cenococcum graniforme*	Genua et al. (1982)
		Endogone pisiformis	Berch and Fortin (1983a)
		Lactarius rufus	Alexander (1981)
		Pisolithus tinctorius	Alexander (1981); Genua et al. (1982); Marx (1977d); Marx et al. (1982); Riffle and Tinus (1982)
		Thelephora terrestris	Riffle and Tinus (1982)
*P. taeda**	Loblolly pine	Nonspecific	Berry and Marx (1977); Lee (1981); Maronek et al. (1981); Marx (1980)
		Cenococcum graniforme	Marx et al. (1978)
		Laccaria laccata	Marx and Davey (1969a)
		Pisolithus tinctorius	Berry and Marx (1976), (1978); Mahoney et al. (1982); Marx (1976), (1977d), (1980); Marx and Artman (1979); Marx and Davey (1969a); Marx et al. (1977), (1978), (1982)
		Suillus luteus	Marx and Davey (1969a)
		Thelephora terrestris	Berry and Marx (1978); Marx and Artman (1979); Marx et al. (1977), (1978)
P. taiwanensis		*Pisolithus tinctorius*	Yang and Wilcox (1984)
		Suillus sublutens	Yang and Wilcox (1984)
P. teocote		*Pisolithus tinctorius*	Marx (1977d)
P. thunbergii	Japanese jack pine	Nonspecific	Lee (1981)
P. virginiana	Scrub pine	Nonspecific	Marx (1975)
		Cenococcum graniforme	Marx (1975), (1976)
		Pisolithus tinctorius	Berry and Marx (1978); Marx (1977d); Marx et al. (1977)
		Thelephora terrestris	Berry and Marx (1978); Marx et al. (1977)
Pisonia	Cockspur	Nonspecific	Powell (1979b)

(Continued)

Table A1 (Continued)

Plant Scientific Name	Plant Common Name	Fungus Scientific Name	References
Pittosporum	Pittosporum	Nonspecific	Maronek et al. (1981)
*Platanus**	Sycamore	Nonspecific	Kormanik et al. (1977b); Kuhns (1980); Marx (1975)
P. occidentalis	Sycamore	*Glomus constrictus*	Kiernan et al. (1983)
		G. etunicatus	Schultz et al. (1981)
		G. fasciculatus	Pope (1980); Schultz et al. (1981)
		G. macrocarpus var. *geosporus*	Kiernan et al. (1983)
Podocarpus macrophylla	Kusamaki	Nonspecific	Maronek et al. (1981)
		G. epigaeus	McGraw and Schenck (1980)
		G. fasciculatus	
		G. macrocarpus	
		G. mosseae	
Pomaderris		Nonspecific	Malloch et al. (1980)
Poncirus	Trifoliate orange		
P. trifoliata	Troyer citrange	Nonspecific	Menge (1983); Menge et al. (1977)
		Glomus fasciculatus	Menge et al. (1977), (1982)
P. trifoliata X		*Glomus constrictus*	Daniels and Menge (1981)
Citrus sinensis		*G. fasciculatus*	Daniels and Menge (1981)
		G. mosseae	Daniels and Menge (1981)
*Populus**	Aspen	Nonspecific	Harris and Jurgenson (1977); Kormanik et al. (1977b); Kuhns (1980); Shuffstall and Medve (1979)
P. balsamifera	Balsam poplar	Nonspecific	Malloch and Malloch (1982)
*P. deltoides**	Cottonwood	*Pisolithus tinctorius*	Navratil and Rochon (1981)
P. deltoides var. *deltoides*		Nonspecific	Kiernan et al. (1983)

(Continued)

Table A1 (Continued)

Plant Scientific Name	Plant Common Name	Fungus Scientific Name	References
P. grandidentata	Large tooth aspen	Nonspecific	Shuffstall and Medve (1979)
		Glomus sp.	Morton and Rizzo (1983)
		G. constrictum	
		G. fasciculatus	
		G. pallidium	
		P. tinctorius	Marx (1975), (1976), (1977d)
P. tremuloides	Quaking aspen	Nonspecific	Malloch and Malloch (1981); Marx (1975); Shuffstall and Medve (1979)
		P. tinctorius	Marx (1976), (1977d)
*P. trichocarpa**	Black cottonwood	*Amanita muscaria*	Molina and Trappe (1982)
		Paxillus involutus	Molina and Trappe (1982)
Pouteria lucentifolia	Sapote	Nonspecific	Janos (1980)
Prosopis			
P. juliflora	Mesquite	*Glomus mosseae*	Bethlenfalvay et al. (1984)
P. spicigera		*Endogone* sp.	Khan (1974)
*Prunus**	Plum	Nonspecific	Malloch et al. (1980); Maronek et al. (1981); Strobel *et al.* (1982)
*P. angustifolia**	Chickasaw plum	*Glomus fasciculatus*	Kiernan et al. (1983)
P. besseyi	Sand cherry	Nonspecific	Barnhill (1981)
P. macrophyllum	Podocarpus	*G. epigaeus*	McGraw and Schenck (1980)
P. munsoniana	Wild-goose plum	Nonspecific	Barnhill (1981)
P. persica	Peach	Nonspecific	Schenck and Kellam (1978)
		Endogone sp.	Gerdemann (1974)
		Gigaspora margarita	McGraw and Schenck (1980); Strobel et al. (1982)
		Glomus epigaeus	McGraw and Schenck (1980)
		G. etunicatus	McGraw and Schenck (1980); Strobel et al. (1982)

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Table A1 (Continued)

Plant Scientific Name	Plant Common Name	Fungus Scientific Name	References
P. persica (cont'd)		*G. fasciculatus*	McGraw and Schenck (1980)
		G. macrocarpus	McGraw and Schenck (1980)
		G. mosseae	Marx (1975); McGraw and Schenck (1980)
		Pisolithus tinctorius	McCouch and Rohde (1982)
P. pensylvanica	Wild red cherry	Nonspecific	Malloch and Malloch (1981), (1982)
*P. serotina**	Black cherry	Nonspecific	Shuffstall and Medve (1979)
		Gigaspora calospora	Kiernan et al. (1983)
		G. gigantea	Kiernan et al. (1983)
		G. pellucida	Kiernan et al. (1983)
		Glomus etunicatu	Schultz et al. (1981)
		G. microcarpus	Kiernan et al. (1983)
		G. mosseae	Schultz et al. (1981)
Pseudotsuga menziesii	Douglas fir	Nonspecific	Berry and Marx (1976); Heilman and Ekuan (1980); Kormanik et al. (1977b); Kuhns (1980); Malloch et al. (1980); Oswald and Ferchau (1968)
		Alpova diplophloeus	Molina and Trappe (1982)
		Amanita muscaria	
		Astraeus pteridis	
		Boletus edulis	
		Cenococcum geophilum	
		C. graniforme	Genua et al. (1982)
		Cortinarius pistorius	Molina and Trappe (1982)
		Hebeloma crustuliniforme	Genua et al. (1982); Trappe (1977)
		Hysterangium separabile	Molina and Trappe (1982)
		Laccaria laccata	Genua et al. (1982); Maronek et al. (1981); Molina and Trappe (1982); Sinclair et al. (1982); Sylvia (1981); Sylvia and Sinclair (1983a), (1983b); Trappe (1977)

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Table A1 (Continued)

Plant Scientific Name	Plant Common Name	Fungus Scientific Name	References
Pseudotsuga menziesii (cont'd)		*Lactarius deliciosus*	Molina and Trappe (1982)
		Leccinum manzanitae	Molina and Trappe (1982)
		Melanogaster intermedius	Molina and Trappe (1982)
		Pisolithus tinctorius	Berry and Marx (1976); Genua et al. (1982); Maronek et al. (1981); Marx (1977d); Molina and Trappe (1982); Trappe (1977)
		Rhizopogon cokeri	Molina and Trappe (1982)
		R. vinicolor	
		Scleroderma hypogaeum	
		Suillus brevipes	
		S. lakei	
		Thelephora terrestris	Trappe (1977)
		Truncocoluonella citrina	Molina and Trappe (1982)
		Zelleromyces gilkeyae	Molina and Trappe (1982)
Psidium quajava	Guava	Nonspecific	Janos (1980); Meador (1977)
Psychotria	Wild coffee	Nonspecific	Malloch et al. (1980)
Purshia tridentata	Purshia	*Acaulospora* sp.	Williams (1979)
		Gigaspora sp.	Williams (1979)
Pyrola	Pyrola		
P. picta f. *picta*		Nonspecific	Largent et al. (1980)
P. picta f. *aphylla*		Nonspecific	Largent et al. (1980)
P. rotundifolia ssp. *maritima*	White lily-of-the-valley	Nonspecific	Read (1983)
P. secunda	One-sided pyrola	Nonspecific	Largent et al. (1980)
*Quercus**	Oaks	Nonspecific	Kormanik et al. (1977b); Kuhns (1980); Marx (1975)

(Continued)

Table A1 (Continued)

Plant Scientific Name	Plant Common Name	Fungus Scientific Name	References
Quercus (cont'd)		*Boletus edulis*	Molina and Trappe (1982)
		Pisolithus tinctorius	Marx (1976), (1977d)
*Q. acutissima**	Sawtooth oak	*Pisolithus tinctorius*	Anderson et al. (1983); Marx (1977d)
		Thelephora terrestris	Anderson et al. (1983)
Q. agrifolia	California live oak	*P. tinctorius*	Marx (1977d)
*Q. alba**	White oak	*Pisolithus tinctorius*	Beckjord et al. (1983); Dixon et al. (1980); Marx (1977d)
		Scleroderma auranteum	Beckjord et al. (1983)
*Q. falcata**	Spanish oak	*P. tinctorius*	
		S. aurantium	
Q. falcata var. *pagodifolia*	Cherrybark oak	*P. tinctorius*	
		S. auranteum	
Q. gambelii	Gambel's oak	*P. tinctorius*	Marx (1977d)
Q. garryana	Oregon white oak	*Melanogaster intermedius*	Molina and Trappe (1982)
Q. laevis	Turkey oak	*P. tinctorius*	Marx (1977d)
Q. lobata	California white oak	*P. tinctorius*	Marx (1977d)
Q. macrocarpa	Bur oak	*Pisolithus tinctorius*	Marx et al. (1982)
*Q. michauxii**	Swamp chestnut oak	*P. tinctorius*	Maronek et al. (1981)
Q. palustris	Pin oak	*P. tinctorius*	Anderson et al. (1983); Maronek and Hendrix (1979); Maronek et al. (1981); Marx (1977d)
Q. robur	English oak	Nonspecific	Zare-Maivan and Gessner (1983)
Q. rubra	Red oak	*P. tinctorius*	Beckjord et al. (1980), (1983); Maronek et al. (1981); Marx (1977d); Ruehl (1980a)
		Scleroderma auranteum	Beckjord et al. (1983)
Q. velutina	Black oak	Nonspecific	Marx (1975)

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Table A1 (Continued)

Plant Scientific Name	Plant Common Name	Fungus Scientific Name	References
Q. velutina (cont'd)		*P. tinctorius*	Dixon et al. (1981a), (1981b), (1981c); Marx (1976), (1977d)
*Q. virginiana**	Live oak	Nonspecific	Meador (1977)
		P. tinctorius	Marx (1977d)
Rhamnus sp.	Buckthorn	Nonspecific	Malloch et al. (1980)
Rhododendron	Rhododendron	Nonspecific	Largent et al. (1980); Moore-Parkhurst and Englander (1982)
R. macrophyllum	Pacific rhododendron	Nonspecific	Largent et al. (1980)
		Cenococcum geophilum	Largent et al. (1980)
R. occidentale		Nonspecific	Largent et al. (1980)
R. ponticum		Nonspecific	Bradley et al. (1982); Read (1983)
		Pizizella ericae	Duddridge and Read (1982)
R. simsii		*Glomus mosseae*	Maronek et al. (1981)
*Rhus**	Sumac		
*R. glabra**	Smooth sumac	Nonspecific	Shuffstall and Medve (1979)
		Acaulospora trappei	Biermann (1983)
*R. radicans**	Poison ivy	Nonspecific	Meador (1977)
R. trilobata (=*R. serotina*)		Nonspecific	Call (1981)
Robinia	Locust	Nonspecific	Kuhns (1980)
R. fertilis	Bristly locust	Nonspecific	Barnhill (1981)
*R. pseudoacacia**	Black locust	*Acaulospora elegans*	Kiernan et al. (1983)
		Gigaspora calospora	
		Glomus aggregatum	
		G. clarus	
		G. constrictus	

(Continued)

Table A1 (Continued)

Plant Scientific Name	Plant Common Name	Fungus Scientific Name	References
R. pseudoacacia (cont'd)		*G. fasciculatus*	Kiernan et al. (1983)
		G. macrocarpus var. *geosporus*	Kiernan et al. (1983)
		G. mosseae	Marx (1975)
Rosa multiflora**	Rose	*Glomus clarus*	Kiernan et al. (1983)
		G. macrocarpus var. *geosporus*	Kiernan et al. (1983)
*Salix**	Willow	Nonspecific	Harris and Jurgensen (1977); Kormanik et al. (1977b); Kuhns (1980); Marshall and Patullo (1981)
S. humilis	Small pussy-willow	Nonspecific	Malloch and Malloch (1981); Marx (1975)
		P. tinctorius	Marx (1976), (1977d)
S. rotundifolia	Dwarf willow	*Cenococcum geophilum*	Antibus et al. (1981)
		C. mucosus	
		Entoloma sericeum	
		Hebeloma pusillum	
		Lactarius lanceolatus	
Salvadora oleoides		*Endogone* sp.	Khan (1974)
Sambucus pubens*	Elderberry	Nonspecific	Malloch and Malloch (1982)
*Sassafras albidum**	Sassafras	Nonspecific	Kiernan et al. (1983); Shuffstall and Medve (1979)
		Glomus fasciculatus	Kiernan et al. (1983)
		G. macrocarpus var. *geosporus*	Kiernan et al. (1983)
		G. microcarpus	Kiernan et al. (1983)
*Schinus terebinthifolius**	Brazilian pepper tree	Nonspecific	Meador (1977)
Sclerolobium		Nonspecific	Malloch et al. (1980)

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Table A1 (Continued)

Plant Scientific Name	Plant Common Name	Fungus Scientific Name	References
Sequoia	Redwood		
S. gigantea (=Sequoiadendron giganteum)	Giant sequoia	Nonspecific	Nicolson and Johnston (1979)
S. sempervirens	Coast redwood	Nonspecific	Nicolson and Johnston (1979)
Simarouba glauca	Paradise tree	Nonspecific	Meador (1977)
Simmondsia chinensis		*Glomus mosseae*	Bethlenfalvay et al. (1984)
Sophora secundiflora	Sophora	Nonspecific	Kuhns (1980)
		Gigaspora sp.	Strong and Davies (1982)
Sorbus		Nonspecific	Kuhns (1980)
S. decora	Mountain ash	Nonspecific	Malloch and Malloch (1981)
Stryphnodendron excelsum		Nonspecific	Janos (1980)
Tachigalia		Nonspecific	Malloch et al. (1980)
Tamarix pentandra	Tamarisk	*Glomus mosseae*	Bethlenfalvay et al. (1984)
		Glomus sp.	Bethlenfalvay et al. (1984)
Taxus baccata	Yew	Nonspecific	Scannerini and Bonfante-Fasolo (1983)
Terminalia	Almond	Nonspecific	Malloch et al. (1980)
Thea chinensis	Tea	Nonspecific	Hayman (1980)
Tilia	Linden, basswood	Nonspecific	Malloch et al. (1980)
Tetrazigia bicolor	Florida tetrazygia	Nonspecific	Meador (1977)
Theobroma cacao	Cacao	Nonspecific	Hayman (1980)
Thuja occidentalis	White cedar	Nonspecific	Malloch and Malloch (1982)
Tsuga	Hemlock		
T. canadensis	Eastern hemlock	*Amanita phalloides*	Kropp and Trappe (1982)
		Boletus edulis	
		B. huronensis	
		B. mirabilis	

(Continued)

Table A1 (Continued)

Plant Scientific Name	Plant Common Name	Fungus Scientific Name	References
T. canadensis (cont'd)		*B. piperatus*	Kropp and Trappe (1982)
		B. radicans	
		B. rubinellus	
		B. subvelutipes	
		Cenococcum geophilum	
		Elaphomyces granulatus	
		E. morrettii	
		Hymenogaster separabile	
		Lactarius pseudoaffinis	
		L. subpurpurascens	
		Pisolithus tinctorius	Kropp and Trappe (1982); Maronek and Hendrix (1980)
		Suillus flavoluteus	Kropp and Trappe (1982)
		S. intermedius	
		Tricholoma matsutake	
T. diversifolia	Japanese hemlock	*Elaphomyces granulatus*	
		Tricholoma matsutake	
T. heterophylla	Western hemlock	Nonspecific	Heilman and Ekuan (1980); Kormanik et al. (1977b); Kuhns (1980); Marx (1977d)
		Albatrellus flettii	Kropp and Trappe (1982)
		Alpova alexsmithii	
		Amanita aspera	
		A. fulva	
		A. gemmata	
		A. muscaria	Kropp and Trappe (1982); Molina and Trappe (1982)
		A. smithiana	

(Continued)

Table A1 (Continued)

Plant Scientific Name	Plant Common Name	Fungus Scientific Name	References
T. heterophylla (cont'd)		*A. vaginata*	Molina and Trappe (1982)
		Astraeus pteridis	Molina and Trappe (1982)
		Barssia oregonensis	Kropp and Trappe (1982)
		Boletus appendiculatus	Kropp and Trappe (1982)
		B. edulis	Molina and Trappe (1982); Kropp and Trappe (1982)
		B. fragrans	Kropp and Trappe (1982)
		B. mirabilis	
		Boletus porosporus var. *americana*	
		B. pulverulentus	
		B. subtomentosus	
		B. zelleri	
		Byssoporia terrestris	
		Camarophyllus borealis	
		Cantharellus cibarius	
		C. tubaeformis	
		Cenococcum geophilum	Christy et al. (1982); Kropp and Trappe (1982)
		Chamonixia caespitosa	Kropp and Trappe (1982)
		Chroogomphus tomentosus	
		Cortinarius delibutus	
		C. griseoviolaceus	
		C. mucosus	
		C. zakii	
		Elaphomyces granulatus	
		E. muricatus	

(Continued)

Table A1 (Continued)

Plant Scientific Name	Plant Common Name	Fungus Scientific Name	References
T. heterophylla (cont'd)		*Gastroboletus subalpinus*	Kropp and Trappe (1982); Molina and Trappe (1982)
		G. turbinatus	Kropp and Trappe (1982)
		Gautieria monticola	
		Genea gardneri	
		G. harknessii	
		Gomphus floccosus	
		Hebeloma crustuliniforme	Kropp and Trappe (1982); Trappe (1977)
		H. mesophaeum	Kropp and Trappe (1982)
		Hydnotrya cubispora	
		H. variiformis	
		Hydnum fuscoindicum	
		Hygrophorus camarophyllus	
		Hymenogaster parksii	
		Hysterangium crassum	
		H. separabile	Kropp and Trappe (1982); Molina and Trappe (1982)
		Inocybe albodisca	Kropp and Trappe (1982)
		I. calamistrata	Kropp and Trappe (1982)
		I. sororia	Kropp and Trappe (1982)
		Laccaria laccata	Kropp and Trappe (1982); Trappe (1977)
		Lactarius deliciosus	Kropp and Trappe (1982); Molina and Trappe (1982)
		L. fallax var. *concolor*	Kropp and Trappe (1982)
		L. glutigriseus	
		L. kauffmanii	
		L. kauffmanii var. *sitchensis*	

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Table A1 (Continued)

Plant Scientific Name	Plant Common Name	Fungus Scientific Name	References
T. heterophylla (cont'd)		*L. pallescens*	Kropp and Trappe (1982)
		L. scrobiculatus	
		L. subviscidus	
		L. substriatus	
		L. trivialis	
		Leucogaster microsporus	
		L. rubescens	
		Leucophleps magnata	
		Macowanites chlorinosmus	
		M. iodiolens	
		Martellia maculata	
		M. parksii	
		M. subfulva	
		Martellia subochracea	
		M. vesiculosa	
		Melanogaster euryspermus	
		M. intermedius	
		Paxillus involutus	Kropp and Trappe (1982); Molina and Trappe (1982)
		Phaeocollybia kauffmanii	Kropp and Trappe (1982)
		Picoa carthusiana	Kropp and Trappe (1982)
		Piloderma croceum	Christy et al. (1982); Kropp and Trappe (1982)
		Pisolithus tinctorius	Kropp and Trappe (1982); Marx (1977d); Marx et al. (1982); Trappe (1977)
		Polyozellus multiplex	Kropp and Trappe (1982)
		Ramaria subbotrytis	Kropp and Trappe (1982)

(Continued)

Table A1 (Continued)

Plant Scientific Name	Plant Common Name	Fungus Scientific Name	References
T. heterophylla (cont'd)		*Rhizopogon colossus*	Kropp and Trappe (1982)
		R. hawkeri	
		R. ochraceisporus	
		R. parksii	
		R. pseudovillosulus	
		R. rubescens	
		R. subgelatinosus	
		R. villosulus	
		R. vinicolor	Kropp and Trappe (1982); Molina and Trappe (1982)
		Russula atrata	Kropp and Trappe (1982)
		R. brevipes	
		R. cascadensis	
		R. decolorans	
		R. dissimulans	
		R. emetica	
		R. fragrantissima	
		R. nigricans	
		Suillus imitatus	
		Thelephora americana	
		T. terrestris	Kropp and Trappe (1982); Trappe (1977)
		T. ponderosum	Kropp and Trappe (1982)
		T. vaccinum	Kropp and Trappe (1982)
		Tylopilus pseudoscaber	Kropp and Trappe (1982)
		Zelleromyces gilkeyae	Kropp and Trappe (1982); Molina and Trappe (1982)
T. mertensiana	Mountain hemlock	*Alpova alexsmithii*	Kropp and Trappe (1982)
		Amanita gemmata	Kropp and Trappe (1982)

(Continued)

Table A1 (Continued)

Plant Scientific Name	Plant Common Name	Fungus Scientific Name	References
T. mertensiana (cont'd)		*A. muscaria*	Kropp and Trappe (1982); Molina and Trappe (1982)
		Boletus calopus var. *frustosus*	Kropp and Trappe (1982)
		B. edulis	Kropp and Trappe (1982); Molina and Trappe (1982)
		B. mirabilis	Kropp and Trappe (1982)
		B. piperatus	
		B. pulverulentus	
		B. rubripes	
		B. smithii	
		B. subtomentosus	
		Camarophyllus tubaeformis	
		Cenococcum geophilum	
		Chroogomphus loculatus	
		Cortinarius montanus	
		C. mutabilis	
		C. phoeniceus var. *occidentalis*	
		C. vibratilis	
		Dentinum repandum	
		Elaphomyces granulatus	
		E. muricatus	
		Endogone lactiflua	
		Gastroboletus imbellus	
		G. subalpinus	Molina and Trappe (1982)

(Continued)

Table A1 (Continued)

Plant Scientific Name	Plant Common Name	Fungus Scientific Name	References
T. mertensiana (cont'd)		*G. turbinatus*	Kropp and Trappe (1982)
		Gautieria monticola	
		G. pterosperma	
		Hydnotrya variiformis	
		Hygrophorus goetzii	
		Hymenogaster brunnescens	
		H. subcaeruleus	
		H. separabile	
		Inocybe xanthomelas	
		Laccaria laccata	Kropp and Trappe (1982); Molina and Trappe (1982)
		Lactarius glutigriseus	Kropp and Trappe (1982)
		L. mucidus	
		L. scrobiculatus	
		Leucophyleps magnata	
		Martellia brunnescens	
		M. fragrans	
		M. idahoensis	
		M. monticola	
		M. subfulva	
		M. vittadinii	
		Radiigera atrogleba	
		Rhizopogon abietis	
		R. atroviolaceus	
		R. cokeri	Kropp and Trappe (1982); Molina and Trappe (1982)
		R. evadens var. *subalpinus*	Kropp and Trappe (1982)

(Continued)

Table A1 (Continued)

Plant Scientific Name	Plant Common Name	Fungus Scientific Name	References
T. mertensiana (cont'd)		*R. milleri*	Kropp and Trappe (1982)
		R. obscurus	
		Rhizopogon smithii	
		R. subcaerulescens	
		R. subpurpurascens	
		R. subalmoneus	
		R. vulgaris	
		Rozites caperata	
		Suillus brevipes	Molina and Trappe (1982)
		S. lakei	Molina and Trappe (1982)
		S. punctatipes	Kropp and Trappe (1982)
		Tricholoma virgatum	
		Trucocolumella rubra	
T. sieboldii	Southern Japanese hemlock	*Tricholoma matsutake*	
		T. robustum	
Ulmus	Elm	Nonspecific	Kormanik et al. (1977b); Kuhns (1980); Malloch et al. (1980)
*Vaccinium**			
V. angustifolium	Blueberry	Nonspecific	Malloch and Malloch (1982); Reich et al. (1982)
V. arbuscula		Nonspecific	Largent et al. (1980)
V. macrocarpon	Cranberry	Nonspecific	Bradley et al. (1982); Read (1983); Stribley and Reed (1975)
V. membranceum		Nonspecific	Largent et al. (1980)
V. occidentalis		Nonspecific	
V. ovatum		Nonspecific	
		Cenococcum geophilum	

(Continued)

(Sheet 43 of 44)

Table A1 (Concluded)

Plant Scientific Name	Plant Common Name	Fungus Scientific Name	References
V. parvifolium		Nonspecific	Largent et al. (1980)
V. scoparium		Nonspecific	Largent et al. (1980)
Viburnum suspensum*	Arrowwood	Nonspecific	Csinos (1981)
Vitis	Grape	Nonspecific	Hayman (1980); Scannerini and Bonfante-Fasolo (1983)
V. aestivalis	Summer grape	Nonspecific	Meador (1977)
*V. labrusca**	Fox grape	*Glomus macrocarpus* var. *geosporus*	Nicolson and Schenck (1979)
V. vinifera		*G. epigeus*	Scannerini and Bonfante-Fasolo (1983)
		G. fasciculatus	Scannerini and Bonfante-Fasolo (1983); Schenck and Kellam (1978)
Zelkova	Zelkova	Nonspecific	Kuhns (1980)

Table A2

Herbaceous Plants Exhibiting Mycorrhizae

Plant Scientific Name	Plant Common Name	Fungus Scientific Name	References
Agava deserti	Aloe	*Glomus epigaeum*	Bethlenfalvay et al. (1984)
		G. mosseae	Bethlenfalvay et al. (1984)
Alhagi			
A. camelorum		*Endogone* sp.	Khan (1974)
A. maurorum		*Endogone* sp.	Khan (1974)
Allium	Onion	Nonspecific	Scannerini and Bonfante-Fasolo (1983)
A. cepa	Common onion	Nonspecific	Yost and Fox (1979)
		Endogone pisiformis	Berch and Fortin (1983a)
		Endogone sp.	Hayman (1974); Nicolson and Johnston (1979)
		Gigaspora calospora	Furlan and Fortin (1977)
		G. margarita	Hirrel and Gerdemann (1980); Schenck (1981)
		Glomus caledonius	Owusu-Bennoah and Mosse (1979)
		G. etunicatus	Hayman (1980); Nelsen (1981); Nelsen et al. (1981)
		G. fasciculatus	Hayman (1983); Hirrel and Gerdemann (1980); Manjunath and Bagyaraj (1981)
		Glomus mosseae	Black and Tinker (1979); Hayman (1983); Rao and Parvathi (1982); Schenck (1981); Schenck and Kellam (1978)
		Glomus sp.	Spitko and Manning (1981)
A. porrum	Leek	*Endogone pisiformis*	Berch and Fortin (1983a)
		Glomus epigaeum	Plenchette et al. (1983a), (1983b)
		G. monosporum	Plenchette et al. (1983a), (1983b)
		G. mosseae	Snellgrove et al. (1982)
Alternanthera philoxeroides	Alligatorweed	Nonspecific	Marx and Davey (1969a)

(Continued)

Table A2 (Continued)

Plant Scientific Name	Plant Common Name	Fungus Scientific Name	References
Ammannia coccinea	Scarlet ammannia	Nonspecific	Meador (1977)
Ampelopsis arborea	Pepper vine	Nonspecific	Meador (1977)
Ananas comosus	Pineapple	Nonspecific	Hayman (1980)
Anemone nemorosa	Anemone	Nonspecific	Read et al. (1976)
Anthyllis vulneraria	Kidney vetch	Nonspecific	Strzemski (1974)
Apocynum androsamifolium	Spreading dogbane	Nonspecific	Malloch and Malloch (1982)
Arachis hypogea	Peanut	*Acaulospora trappei*	Nicolson and Schenck (1979)
		Glomus clarus	Nicolson and Schenck (1979)
		G. mosseae	Rao and Parvathi (1982)
Artemisia maritima	Wormwood	*Endogone* sp.	Khan (1974)
Asparagus officinalis	Asparagus	*Glomus constrictus*	Daniels and Menge (1981)
		G. epigaeus	
		G. fasciculatus	
		G. mosseae	
Aster	Aster		
A. macrophyllus		Nonspecific	Malloch and Malloch (1982)
A. tripolium		Nonspecific	Hayman (1974)
Astragalus	Milk-vetch		
A. psilacanthus		*Endogone* sp.	Khan (1974)
A. tribuloides		*Endogone* sp.	Khan (1974)
Bacopa monnieri	Water-hyssop	*Glomus mosseae*	Bagyaraj et al. (1979b); McGraw and Schenck (1981)
Bidens pilosa	Bur-marigold	Nonspecific	Meador (1977)
Blackstonia perfoliata		Nonspecific	Gay et al. (1982)
Brickellia frutescens		*Glomus fasciculatum*	Bethlenfalvay et al. (1984)
		G. mosseae	Bethlenfalvay et al. (1984)

(Continued)

Table A2 (Continued)

Plant Scientific Name	Plant Common Name	Fungus Scientific Name	References
Bupleurum falcatum	Thoroughwax	Nonspecific	Hayman (1974)
Cajunus cajan	Pigeon-pea	*G. mosseae*	Zambolin and Schenck (1983)
Callitriche hamulata	Water-starwort	Nonspecific	Sondergaard and Laegaard (1977)
Calluna vulgaris	Heather	Nonspecific	Bradley et al. (1982)
Calotropis procera		*Endogone* sp.	Khan (1974)
Campanula rotundifolia	Harebell	Nonspecific	Read et al. (1976)
Capsicum annuum	Bellpepper	*G. fasciculatus*	Hirrel and Gerdemann (1980)
		Gigaspora margarita	Hirrel and Gerdemann (1980)
Capsicum fruticosum	Pepper	*Glomus mosseae*	Marx (1975)
Carludovica palmata		Nonspecific	Janos (1980)
Cassia			
C. armata		*G. epigaeum*	Bethlenfalvay et al. (1984)
		Glomus sp.	Bethlenfalvay et al. (1984)
C. fructicosa		Nonspecific	Janos (1980)
Castilla elastica		Nonspecific	Janos (1980)
Centaurea nigra	Knapweed	Nonspecific	Read et al. (1976)
Centaurium erythraea	Centaury	Nonspecific	Gay et al. (1982)
Centrosema sp.	Butterfly pea	Nonspecific	Hayman (1980)
		G. epigaeus	McGraw and Schenck (1981)
		G. etunicatus	McGraw and Schenck (1981)
Chrysanthemum morifolium	Chrysanthemum	*Glomus fasciculatus*	Johnson et al. (1982a); McGraw and Schenck (1981)
		G. macrocarpus	McGraw and Schenck (1981)
		G. mosseae	McGraw and Schenck (1981)
Circaea alpine	Enchanter's nightshade	Nonspecific	Hayman (1974)
Clintonia borealis	Bluebead-lily	Nonspecific	Malloch and Malloch (1981)
Convolvulus spinosus		*Endogone* sp.	Khan (1974)

(Continued)

Table A2 (Continued)

Plant Scientific Name	Plant Common Name	Fungus Scientific Name	References
Coptis trifoliata	Goldthread	Nonspecific	Malloch and Malloch (1981)
Cyanotis cristata		*Glomus macrocarpus*	Bagyaraj et al. (1979b); McGraw and Schenck (1981)
Dactylorhiza maculata	Orchid	Nonspecific	Scannerini and Bonfante-Fasolo (1983)
Daucus carota	Carrot	*G. mosseae*	Schenck and Kellam (1978)
Echinocactus acanthodes		*G. epigaeum*	Bethlenfalvay et al. (1984)
		G. intraradices	
		G. mosseae	
		Glomus sp.	
Echinocereus engelmannii	Cactus	*Glomus epigaeum*	
		Glomus sp.	
Echinops echinatus	Globe-thistle	*Endogone* sp.	Khan (1974)
Eichhornia crassipes	Waterhyacinth	Nonspecific	Spitko, Tattar, and Rohde (1978)
Epilobium angustifolium	Fireweed	Nonspecific	Malloch and Malloch (1982)
Eremostachys leasifolia		*Endogone* sp.	Khan (1974)
Eriogonum sp.	Umbrella-plant	Nonspecific	Malloch et al. (1980)
E. fasciculatum		*Glomus epigaeum*	Bethlenfalvay et al. (1984)
		Glomus mosseae	Bethlenfalvay et al. (1984)
E. nodosum		*G. mosseae*	Bethlenfalvay et al. (1984)
Eupatorium coelestinum	Mistflower	Nonspecific	Meador (1977)
Euphorbia	Spurge		
E. polycarpa		*Glomus epigaeum*	Bethlenfalvay et al. (1984)
		Glomus sp.	Bethlenfalvay et al. (1984)
E. pulcherrima	Poinsettia	*G. mosseae*	Schenck (1981); Schenck and Kellam (1978)
		Gigaspora margarita	Maronek et al. (1981)
Euphrasia officinalis	Eyebright	Nonspecific	Read et al. (1976)

(Continued)

Table A2 (Continued)

Plant Scientific Name	Plant Common Name	Fungus Scientific Name	References
Filipendula ulmaria	Queen-of-the-meadow	Nonspecific	Read et al. (1976)
Fragaria sp.	Strawberry	*Endogone* sp.	Gerdemann (1974)
F. chiloensis var. *ananassa*	Cultivated strawberry	Nonspecific	Schenck and Kellam (1978)
F. vesca	Woodland strawberry	Nonspecific	Schenck and Kellam (1978)
Franseria dumosa		*Glomus epigaeum*	Bethlenfalvay et al. (1984)
		Glomus sp.	Bethlenfalvay et al. (1984)
Galium	Bedstraw		
G. sexatile	Heath-bedstraw	Nonspecific	Read et al. (1976)
G. sterneri		Nonspecific	Read et al. (1976)
G. triflorum	Sweet-scented bedstraw	Nonspecific	Malloch and Malloch (1982)
Gentianella amarella (=*Gentiana amarella*)	Felwort	Nonspecific	Gay et al. (1982)
Geranium robertianum	Geranium	Nonspecific	Read et al. (1976)
Glycine			
G. hispida		Nonspecific	Strzemski (1974)
*G. max**	Soybean	Nonspecific	Schenck and Kellam (1978)
		Endogone sp.	Gerdemann (1974)
		Gigaspora gigantea	Carling and Brown (1980); Nicolson and Johnston (1979); Ross (1980)
		G. heterogama	Schenck and Kellam (1978)
		G. margarita	Schenck and Kellam (1978)
		Glomus caledonius	Carling and Brown (1980)

(Continued)

* All genera and species followed by an asterisk in this table were listed by Landin (1978) as "Selected Upland Plant Species for Habitat Development on Dredged Material Sites." When only the genus exhibits an asterisk, Landin has listed a different species from the one (if any) cited here.

Table A2 (Continued)

Plant Scientific Name	Plant Common Name	Fungus Scientific Name	References
G. max (cont'd)		*G. clarus*	Nicolson and Schenck (1979)
		G. epigaeus	Carling and Brown (1980)
		G. etunicatus	Carling and Brown (1980); Schenck (1981)
		G. fasciculatus	Bagyaraj et al. (1979a); Bethlenfalvay et al. (1981), (1982b), (1982c); Carling and Brown (1980); Carling et al. (1979); Groth and Martinson (1983); Nicolson and Schenck (1979); Yost and Fox (1982)
		G. geosporum	Brewer and Heagle (1983)
		G. macrocarpus	Schenck and Kellam (1978)
		G. macrocarpus var. *geosporus*	Nicolson and Schenck (1979); Ross (1980); Schneck and Kellam (1978)
		Glomus mosseae	Asimi et al. (1980); Carling and Brown (1980); Gianinazzi-Pearson et al. (1981); Groth and Martinson (1983); Marx (1975); Nicolson and Schenck (1979); Schenck and Kellam (1978); Zambolin and Schenck (1983)
		G. microcarpus	Carling and Brown (1980)
Gossypium hirsutum	Cotton	*Acaulospora trappei*	Nicolson and Schenck (1979)
		Gigaspora margarita	Pugh et al. (1981); Schenck and Kellam (1978)
		Glomus constrictus	Daniels and Menge (1981)
		G. epigaeus	Daniels and Menge (1981)
		G. fasciculatus	Bagyaraj and Manjunath (1980); Daniels and Menge (1981); Schenck (1981)
		G. mosseae	Daniels and Menge (1981); Marx (1975); Schenck and Kellam (1978)
Gurania spinulosa		Nonspecific	Janos (1980)
Guthierezzia sarothrae		*G. fasciculatum*	Bethlenfalvay et al. (1984)
		G. mosseae	Bethlenfalvay et al. (1984)

(Continued)

Table A2 (Continued)

Plant Scientific Name	Plant Common Name	Fungus Scientific Name	References
Gymnocarpium dryopteris		Nonspecific	Malloch and Malloch (1982)
Hampea appendiculata		Nonspecific	Janos (1980)
Helianthemum chamaecistus	Rockrose	Nonspecific	Read et al. (1976)
Heliotropium ophioglossum	Turnsole	*Endogone* sp.	Khan (1974)
Hertia intermedia		*Endogone* sp.	Khan (1974)
Hieracium pilosella	Mouse-ear	Nonspecific	Read et al. (1976)
Hydrocotyle bonariensis	Water pennywort	Nonspecific	Koske (1975)
Hymenoclea salsola		*Glomus epigaeum*	Bethlenfalvay et al. (1984)
		Glomus sp.	Bethlenfalvay et al. (1984)
Hyptis	Bittermints		
H. capitata		Nonspecific	Janos (1980)
H. obtusiflora		Nonspecific	Janos (1980)
Inula grantioides		*Endogone* sp.	Khan (1974)
Ipomoea pes-caprae	Morning-glory	*Endogone* sp.	Khan (1974)
Iris stocksii	Iris	*Endogone* sp.	Khan (1974)
Isoetes lacustris	Quillwort	Nonspecific	Sondergaard and Laegaard (1977)
Isomeris arborea		*G. mosseae*	Bethlenfalvay et al. (1984)
Lathyrus	Vetchling		
L. japonicus var. *glaber*		*Acaulospora scrobiculata*	Koske (1981)
		Gigaspora calospora	
		G. gigantea	
		Gigaspora sp.	
		Glomus etunicatus	
		G. fasciculatus	
L. sylvestris	Flatpea	Nonspecific	Lambert and Cole (1980)
Launaea procumbens		*Endogone* sp.	Khan (1974)

(Continued)

Table A2 (Continued)

Plant Scientific Name	Plant Common Name	Fungus Scientific Name	References
Lens esculenta	Lentil	Nonspecific	Strzemski (1974)
Leontodon hispidus	Hawkbit	Nonspecific	Read et al. (1976)
Lepidospartum squamatum		*Glomus fasciculatum*	Bethlenfalvay et al. (1984)
		G. intraradices	Bethlenfalvay et al. (1984)
		G. mosseae	Bethlenfalvay et al. (1984)
Lespedeza bicolor	Bush-clover	Nonspecific	Barnhill (1981)
Lilium longiflorum	Easter lily	*Acaulospora trappei*	Maronek et al. (1981)
Linnaea borealis	Twinflower	Nonspecific	Malloch and Malloch (1981)
Linum catharticum	Fairy-flax	Nonspecific	Read et al. (1976)
Littorella uniflora (=*L. americana*)		Nonspecific	Sondergaard and Laegaard (1977)
Lobelia dortmanna	Water-lobelia	Nonspecific	Sondergaard and Laegaard (1977)
Lotus	Birdsfoot trefoil		
L. corniculatus		Nonspecific	Lambert and Cole (1980); Lambert et al. (1980a); Read et al. (1976); Strzemski (1974)
L. pedunculatus	Grasslands maku	*Gigaspora margarita*	Powell and Sithamparanathan (1977)
L. uliginosus	Greater birdsfoot trefoil	Nonspecific	Strzemski (1974)
		Glomus fasciculatus	Powell and Daniel (1978)
Ludwigia	False loosestrife		
L. adscendens		Nonspecific	Bagyaraj et al. (1979b)
L. octovalvis		Nonspecific	Meador (1977)
L. peruviana	Primrose willow	Nonspecific	Meador (1977)
Luffa actangula	Angular gourd	*Glomus mosseae*	Rao and Parvathi (1982)
Lycopersicon esculentum	Common tomato	Nonspecific	Phillips and Hayman (1970)
		Glomus constrictus	Daniels and Menge (1981)
		G. epigaeus	Daniels and Menge (1981); McGraw and Schenck (1981)

(Continued)

Table A2 (Continued)

Plant Scientific Name	Plant Common Name	Fungus Scientific Name	References
Lycopersicon esculentum (cont'd)		*G. etunicatus*	McGraw and Schenck (1981)
		G. fasciculatus	Bagyaraj and Menge (1978); Daniels and Menge (1981); McGraw and Schenck (1981)
		G. macrocarpus	McGraw and Schenck (1981)
		G. mosseae	Daniels and Menge (1981); McGraw and Schenck (1981); Rao and Parvathi (1982); Schenck (1981); Schenck and Kellam (1978)
Maianthemum canadense	False lily-of-the-valley	Nonspecific	Malloch and Malloch (1981)
Manihot esculenta	Cassava	Nonspecific	Hayman (1980); Howeler et al. (1982); Yost and Fox (1979)
		Glomus mosseae	Kang et al. (1980)
Medicago			
M. lupulina	Black medic	Nonspecific	Read et al. (1976); Strzemski (1974)
*M. sativa**	Alfalfa, lucerne	Nonspecific	Lambert et al. (1980c); Smith and Bowen (1979); Schenck and Kellam (1978)
		Acaulospora laevis	Schenck and Kellam (1978)
		A. trappei	O'Bannon et al. (1980)
		Gigaspora margarita	Carling and Brown (1980)
		Glomus caledonius	Owusu-Bennoah and Mosse (1979)
		G. deserticola	Steinberg (1982)
		G. epigaeus	O'Bannon et al. (1980)
		G. fasciculatus	Lambert et al. (1980b); O'Bannon et al. (1980); Steinberg (1982)
		G. monosporus	O'Bannon et al. (1980)
		G. mosseae	Azcon-Aquilar and Barea (1981); Barea and Azcon-Aquilar (1982); Black and Tinker (1979); Lambert et al. (1980b); O'Bannon et al. (1980); Steinberg (1982)

(Continued)

Table A2 (Continued)

Plant Scientific Name	Plant Common Name	Fungus Scientific Name	References
Melilotus albus	Melilot, sweet clover	Nonspecific	Koske et al. (1975); Meador (1977); Stremski (1974)
Mercurialis perennis	Mercury	Nonspecific	Read et al. (1976)
Myriophyllum alterniflorum	Watermilfoil	Nonspecific	Sondergaard and Laegaard (1977)
Nerium indicum		*Endogone* sp.	Khan (1974)
Nicotiana tabacum	Tobacco	Nonspecific	Phillips and Hayman (1970); Scannerini and Bonfante-Fasolo (1983)
		Acaulospora gerdemannii	Nicolson and Schenck (1979)
		A. trappei	Nicolson and Schenck (1979)
		Gigaspora gigantea	Schenck and Kellam (1978)
		G. margarita	Csinos (1981)
		Glomus margarita	Nicolson and Schenck (1979)
		Glomus microcarpus	Nicolson and Schenck (1979)
		G. mosseae	Schenck (1981); Schenck and Kellam (1978)
Nymphaea stellata	Waterlily	Nonspecific	Bagyaraj et al. (1979b)
Ogcodeia naga		Nonspecific	Janos (1980)
Onobrychis sativa	Sainfoin	Nonspecific	Strzemski (1974)
Opuntia	Cactus		
O. acanthocarpa		*G. epigaeum*	Bethlenfalvay et al. (1984)
		Glomus sp.	
O. basilaris		*G. mosseae*	
O. bigelovii		*G. epigaeum*	
		Glomus sp.	
O. echinocarpa		*G. epigaeum*	
		G. mosseae	
O. rhodantha	Prickly pear	Nonspecific	Call (1981); Call and McKell (1982)

(Continued)

Table A2 (Continued)

Plant Scientific Name	Plant Common Name	Fungus Scientific Name	References
Ornithogalum	Star-of-bethlehem	Nonspecific	Scannerini and Bonfante-Fasolo (1983)
O. umbellatum	Nap-at-noon	*G. fasciculatus*	Scannerini and Bonfante-Fasolo (1983)
Ornithopus sativus	Common serradella	Nonspecific	Strzemski (1974)
Oxalis acetosella (=*O. montana*)	Common wood-sorrel	Nonspecific	Hayman (1974)
Pelalonix thurberi		*Glomus mosseae*	Bethlenfalvay et al. (1984)
		Glomus sp.	Bethlenfalvay et al. (1984)
Pentaclethra			
P. macroloba		Nonspecific	Janos (1980)
Periploca aphylla	Silkvine	*Endogone* sp.	Khan (1974)
Petasites palmatus	Sweet coltsfoot	Nonspecific	Malloch and Malloch (1982)
Petunia violacea	Petunia	Nonspecific	Schenck and Kellam (1978)
Phaseolus	Kidney-bean		
P. aureus	Green gram	*G. mosseae*	Rao and Parvathi (1982)
P. mungo	Black gram	*G. mosseae*	Rao and Parvathi (1982)
P. vulgaris	Common bean	Nonspecific	Howeler et al. (1982); Phillips and Hayman (1970); Scannerini and Bonfante-Fasolo (1983); Strzemski (1974); Sutton and Sheppard (1976)
		G. fasciculatus	Bethlenfalvay et al. (1982a)
		Glomus sp.	Clough and Sutton (1978); Sutton and Sheppard (1976)
Pisum (=*Lathyrus*)	Vetchling		
P. arvense	Field pea	Nonspecific	Strzemski (1974)
P. sativum	Garden pea	Nonspecific	Scannerini and Bonfante-Fasolo (1983); Stremski (1974)
Pithecellobium longifolium	Cat claw	Nonspecific	Janos (1980)

(Continued)

Table A2 (Continued)

Plant Scientific Name	Plant Common Name	Fungus Scientific Name	References
Plantago	Plantain		
P. lanceolata	Ribgrass	Nonspecific	Christie et al. (1978); Whittingham and Read (1982)
P. ovata	Isbagol	*Glomus fasciculatus*	Mexal (1980)
		G. macrocarpus	Mexal (1980)
		G. mosseae	Mexal (1980)
Ponteria lucentifolia		Nonspecific	Janos (1980)
Potentilla	Cinquefoil		
P. erecta		Nonspecific	Read et al. (1976)
P. tabernaemontani		Nonspecific	Read et al. (1976)
Poterium sanguisorba (=*Sanguisorba minor*)	Garden burnet	Nonspecific	Read et al. (1976)
Pteridium aquilinum	Bracken fern	Nonspecific	Malloch and Malloch (1981)
Pueraria phaseoloides		Nonspecific	Waidyanatha and Ariyaratne (1979)
Pyrola secund	Shinleaf	Nonspecific	Malloch and Malloch (1982)
Rhazya stricta	Dogbane	*Endogone* sp.	Khan (1974)
Rubus	Bramble		
R. idaeus	Raspberry	Nonspecific	Scannerini and Bonfante-Fasolo (1983)
		G. fasciculatus	Morandi et al. (1979); Hughes et al. (1979)
		G. mosseae	Morandi et al. (1979)
		G. tenuis	Morandi et al. (1979)
R. saxatilis		Nonspecific	Read et al. (1976)
Salvinia cucullata	Salvinia	Nonspecific	Bagyaraj et al. (1979b)
Sanguisorba minor	Garden-burnet	Nonspecific	Gay et al. (1982)
Sarcobatus vermiculatus		Nonspecific	Call (1981); Call and McKell (1982)
Sickingia maxonii		Nonspecific	Janos (1980)

(Continued)

Table A2 (Continued)

Plant Scientific Name	Plant Common Name	Fungus Scientific Name	References
Sida rhombifolia		Nonspecific	Janos (1980)
Solanum	Nightshade		
S. quitoense		Nonspecific	
S. rugosum		Nonspecific	
S. surattense		*Endogone* sp.	Khan (1974)
S. tuberosum	Potato	Nonspecific	Hayman (1980); Ocampo and Hayman (1980)
		Glomus macrocarpus	Swaminathan and Verma (1979)
Solidago (=*Brachystegia*)	Goldenrod	Nonspecific	Mahloch et al. (1980)
S. sempervirens	Seaside goldenrod	*Acaulospora scrobiculata*	Koske (1981)
		Gigaspora gigantea	
		Gigaspora sp.	
		Glomus etunicatus	
		G. fasciculatus	
Soracea pubivena		Nonspecific	Janos (1980)
Sphagnum sp.		*Endogone pisiformis*	Berch and Fortin (1983a)
Stemmadenia donnell-smithii		Nonspecific	Janos (1980)
Streptopus roseus	Rose mandarin	Nonspecific	Malloch and Malloch (1982)
Stylosanthes spp.	Wild bean	Nonspecific	Hayman (1980)
S. guyanensis		Nonspecific	Waidyanatha and Ariyaratne (1979)
S. hamata		Nonspecific	Yost and Fox (1979)
Tagetes palulus	Marigold	*G. monosporum*	Plenchette et al. (1983a), (1983b)
Tetrademia canescans		Nonspecific	Call (1981); Call and McKell (1982)
Terminalis oblonga		Nonspecific	Janos (1980)
Teucrium scorodonia	Wood-sage	Nonspecific	Read et al. (1976)
Thymus drucei	Thyme	Nonspecific	Read et al. (1976)

(Continued)

Table A2 (Continued)

Plant Scientific Name	Plant Common Name	Fungus Scientific Name	References
Trientalis borealis	Starflower	Nonspecific	Malloch and Malloch (1981)
Trifolium spp.	Clover	*Endogone* sp.	Koske et al. (1975)
		Glomus etunicatus	Rangeley et al. (1982)
		G. mosseae	Rangeley et al. (1982)
T. hybridum	Swedish clover	Nonspecific	Strzemski (1)974
	Alsike clover	*Acaulospora laevis*	Schenck and Kellam (1978)
*T. pratense**	Red clover	Nonspecific	Strzemski (1974)
		Endogone sp.	Gerdemann (1974)
		Gigaspora margarita	Powell and Sithamparanathan (1977)
		Glomus etunicatus	Rangeley et al. (1982)
		G. gigantea	Lambert et al. (1980b)
*T. repens**	White clover	Nonspecific	Christie et al. (1978); Scannerini and Bonfante-Fasolo (1983); Strzemski (1974); Tisdall and Oades (1979)
		Gigaspora margarita	Buwalda (1980); Crush and Caradus (1980); Powell and Daniel (1978); Powell and Sithamparanathan (1977)
		Glomus fasciculatus	Crush and Caradus (1980); Hayman and Mosse (1979); Powell and Daniel (1978)
		Glomus mosseae	Crush and Caradus (1980); Hayman and Mosse (1979)
		G. tenuis	Buwalda (1980); Powell and Daniel (1978)
T. subterraneum	Subterraneam clover	Nonspecific	Chambers et al. (1980a), (1980b); Smith (1982); Smith and Bowen (1979); Smith and Smith (1981)
		Glomus caledonium	Beilby (1983)
		G. fasciculatus	Abbott and Robson (1978)
		G. monosporus	Abbott and Robson (1978)
		G. mosseae (=Endogone mosseae)	Bevege et al. (1975); Chambers et al. (1980a) (1980b)

(Continued)

Table A2 (Concluded)

Plant Scientific Name	Plant Common Name	Fungus Scientific Name	References
Trigonella faenumgraecum	Fenugreek	Nonspecific	Strzemski (1974)
Veconcibea pleiostemona		Nonspecific	Janos (1980)
Verbascum erianthum	Mullein	*Endogone* sp.	Khan (1974)
Vernonia	Ironweed		
V. cinerea		*Endogone* sp.	Khan (1974)
V. chamaedrys	Bird's-eye	Nonspecific	Read et al. (1976)
Vicia	Vetch		
V. faba major	Broad bean	Nonspecific	Strzemski (1974)
V. fabra minor	Horse bean	Nonspecific	
V. sativa	Common vetch	Nonspecific	
V. villosa	Hairy vetch	Nonspecific	
Vigna unguiculata	Cowpea	Nonspecific	Howeler et al. (1982); Yost and Fox (1979)
Viola	Violet		
V. biflora		Nonspecific	Hayman (1974)
V. lutea		Nonspecific	Read et al. (1976)
V. renifolia		Nonspecific	Malloch and Malloch (1982)
V. riviniana		Nonspecific	Read et al. (1976)
Virole koschnyi		Nonspecific	Janos (1980)
Withania			
W. coagulans		*Endogone* sp.	Khan (1974)
W. somnifera		*Endogone* sp.	Khan (1974)
Yucca schidigera	Yucca	*Glomus intraradices*	Bethlenfalvay et al. (1984)
		G. mosseae	Bethlenfalvay et al. (1984)
Ziziphus			
Z. jujuba		*Endogone* sp.	Khan (1974)
Z. nummularia		*Endogone* sp.	Khan (1974)
Z. rotundifolia		*Endogone* sp.	Khan (1974)

(Sheet 15 of 15)

Table A3

Grasses, Sedges, and Rushes Exhibiting Mycorrhizae

Plant Scientific Name	Plant Common Name	Fungus Scientific Name	References
Agropyron			
A. junceiforme		*Glomus fasciculatus*	Nicolson and Johnston (1979)
		G. macrocarpus	Nicolson and Johnston (1979)
A. smithii		Nonspecific	Call (1981); Call and McKell (1982)
A. trachycaulum		Nonspecific	Zak and Parkinson (1982), (1983)
Agrostis	Bentgrass		
A. campestris		Nonspecific	Read et al. (1976)
A. tenuis	Rhode Island bentgrass	Nonspecific	Lawley et al. (1982); Read et al. (1976)
Ammophila	Sand-reed		
*A. arenaria**	European beachgrass	*G. fasciculatus*	Nicolson and Johnston (1979)
		G. macrocarpus	Nicolson and Johnston (1979)
A. breviligulata	Beachgrass	*Acaulospora scrobiculata*	Koske (1981)
		Gigaspora calospora	
		G. gigantea	
		Gigaspora sp.	
		Glomus etunicatus	
		G. fasciculatus	
Andropogon sp.	Beardgrass	*Glomus* sp.	Clough and Sutton (1978); Sutton and Sheppard (1976)
Anthoxanthum odoratum	Sweet vernal grass	Nonspecific	Christie et al. (1978); Read et al. (1976)
Arrhenantherum elatius	Tall oatgrass	Nonspecific	Read et al. (1976)

(Continued)

* All genera and species followed by an asterisk in this table were listed by Landin (1978) as "Selected Upland Plant Species for Habitat Development on Dredged Material Sites." When only the genus exhibits an asterisk, Landin has listed a different species from the one (if any) cited here.

(Sheet 1 of 8)

Table A3 (Continued)

Plant Scientific Name	Plant Common Name	Fungus Scientific Name	References
Avena sativa	Oats	Nonspecific	Schenck and Kellam (1978); Strzemski (1974)
Bromus	Brome-grass		
B. catharticus	Prairie grass	*Gigaspora margarita*	Powell and Sithamparanathan (1977)
B. erectus		Nonspecific	Read et al. (1976)
B. tectorus		Nonspecific	Call (1981); Call and McKell (1982)
Bouteloua gracilis	Rangeland grass	*Glomus fasciculatus*	Allen (1982); Allen et al. (1981)
Briza media	Quaking grass	Nonspecific	Read et al. (1976)
Calamagrostis canadensis	Reed grass	Nonspecific	Malloch and Malloch (1982)
		Endogone sp.	Koske et al. (1975)
Calamovilfa longiflora		*G.* sp.	Clough and Sutton (1978); Sutton and Sheppard (1976)
Carex flacca	Sedge	Nonspecific	Gay et al. (1982); Read et al. (1976)
Cenchrus pennisetiformis	Sandbur	*Endogone* sp.	Khan (1974)
Cyperus eleusinoides	Galingale	*G. etunicatus*	Bagyaraj et al. (1979b); McGraw and Schenck (1981)
Dactylis glomerata	Orchard-grass	*Endogone* sp.	Koske et al. (1975)
Deschampsia	Hairgrass		
D. caespitosa	Tufted hairgrass	Nonspecific	Read et al. (1976)
D. flexuosa	Common hairgrass	Nonspecific	Abbott and Robson (1978); Read et al. (1976)
Digitaria decumbens	Pangola digit grass	*Sclerocystis coremioides*	Nicolson and Schenck (1979)
Echinochloa colonum	Jungle rice	*G. epigaeus*	Bagyaraj et al. (1979b); McGraw and Schenck (1981)
Eleochoris palustris	Spike-rush	Nonspecific	Sondergaard and Laegaard (1977)
Eleusine covacana	Finger millet	*Glomus fasciculatus*	Bagyaraj and Manjunath (1980)
Elymus sp.	Rye	Nonspecific	Strzemski (1974)

(Continued)

Table A3 (Continued)

Plant Scientific Name	Plant Common Name	Fungus Scientific Name	References
Festuca	Fescue-grass		
F. arizonica		*Gigaspora calospora*	Molina and Trappe (1978)
		Glomus fasciculatus	
		G. macrocarpus var. *geosporus*	
		G. macrocarpus var. *macrocarpus*	
		Glomus microcarpus	
		G. mosseae	
		Sclerocystis rubiformis	
F. arundinacea	Tall fescue	Nonspecific	Lambert and Cole (1980)
		Gigaspora margarita	Powell and Sithamparanathan (1977)
F. idahoensis		*Acaulospora laevis*	Molina and Trappe (1978)
		Gigaspora calospora	
		Glomus fasciculatus	
		G. macrocarpus var. *macrocarpus*	
		G. microcarpus	
		G. mosseae	
		G. tenuis	
F. littoralis		Nonspecific	Koske (1975)
F. occidentalis		*G. mosseae*	Ho and Trappe (1975)
F. ovina	Sheep's-fescue	Nonspecific	Gay et al. (1982); Lawley et al. (1982); Read et al. (1976); Whittingham and Read (1982)
F. rubra	Rough fescue	nonspecific	Read et al. (1976)
F. scabnella		*Acaulospora laevis*	Molina and Trappe (1978)
		Gigaspora calospora	Molina and Trappe (1978)

(Continued)

Table A3 (Continued)

Plant Scientific Name	Plant Common Name	Fungus Scientific Name	References
F. scabnella (cont'd)		*Glomus fasciculatus*	Molina and Trappe (1978)
		G. macrocarpus var. *macrocarpus*	
		G. microcarpus	
		G. mosseae	
		G. tenuis	
F. turberi		*A. laevis*	
		Gigaspora calospora	
		Glomus fasciculatus	
		G. macrocarpus var. *macrocarpus*	
F. viridula		*A. laevis*	
		A. scrobiculata	
		Gigaspora calospora	
		Glomus fasciculatus	
		Glomus macrocarpus var. *geosporus*	
		G. macrocarpus var. *macrocarpus*	
		G. microcarpus	
		G. tenuis	
Glyceria plicata	Manna-grass	Nonspecific	Read et al. (1976)
Helictotrichon pubescens		Nonspecific	Read et al. (1976)
Hilaria rigida		*G. mosseae*	Bethlenfalvay et al. (1984)
Holcus lanatus	Velvet-grass	Nonspecific	Read et al. (1976)
Hordeum	Barley		
H. distichon		*G. caledonius*	Owusu-Bennoah and Mosse (1979)

(Continued)

Table A3 (Continued)

Plant Scientific Name	Plant Common Name	Fungus Scientific Name	References
H. distichon (cont'd)		*G. mosseae*	Black and Tinker (1979)
*H. vulgare**	Cultivated barley	Nonspecific	Hayman (1980); Jensen and Jakobsen (1980); Ocampo and Hayman (1980); Strzemski (1974)
		Gigaspora margarita	Powell (1981)
		Glomus caledonius	Owusu-Bennoah and Mosse (1979)
		G. constrictus	Jensen (1982)
		G. fasciculatus	Jensen (1982); Powell (1981)
		G. margarita	Jensen (1982)
		G. mosseae	Black and Tinker (1979); Jakobsen and Anderson (1982); Powell (1981)
Koeleria cristata		Nonspecific	Read et al. (1976)
*Lolium perenne**	Rye grass	Nonspecific	Christie et al. (1978); Lambert and Cole (1980); Ponder (1979), (1980); Read et al. (1976); Tisdall and Oades (1979)
		Gigaspora margarita	Buwalda (1980); Powell (1979a)
		Glomus tenuis	Buwalda (1980); Powell (1979a)
Luzula	Woodrush		
L. campestris (=L. bulbosa)		Nonspecific	Read et al. (1976)
L. pilosa		Nonspecific	Read et al. (1976)
Macroptilium atropurpureum	Siratro	*Gigaspora margarita*	Lopes et al. (1980)
Nardus stricta	Matgrass	Nonspecific	Phillips and Hayman (1970); Read et al. (1976)
		Glomus mosseae	Hepper and Smith (1976)
Oryza sativa	Rice	Nonspecific	Howeler et al. (1982)
Oryzopsis	Mountain rice		
O. asperifolia		Nonspecific	Malloch and Malloch (1981)

(Continued)

Table A3 (Continued)

Plant Scientific Name	Plant Common Name	Fungus Scientific Name	References
O. hymenoides	Silkgrass	Nonspecific	Call (1981); Call and McKell (1982)
Panicum	Panic-grass		
P. bartowense	Fall panic-grass	Nonspecific	Meador (1977)
P. maximum		*Glomus fasciculatum*	Krisna and Bagyaraj (1983)
P. purpurascens (=*Brachiaria purpurascens*)	Para grass	Nonspecific	Meador (1977)
*Paspalum notatum**	Bahia grass	Nonspecific	Abbott and Robson (1977)
		Acaulospora gerdemannii	Nicolson and Schenck (1979)
		Gigaspora gregaria	
		G. nigra	
		G. sinuosa	
		Glomus clarus	
		G. fasciculatus	
		G. fulvus	
		G. gerdemannii	
		G. macrocarpus var. *geosporus*	
		G. pellucida	
		G. rosea	
		G. tenuis	
Pennisetum typhoideum	Pearl millet	*G. mosseae*	Rao and Parvathi (1982)
Phalaris	Canary-grass		
P. arundinacea	Reed canary-grass	Nonspecific	Read et al. (1976)
P. tuberosa		*Gigaspora margarita*	Powell and Sithamparanathan (1977)
Phragmites australis	Common reed	Nonspecific	Sondergaard and Laegaard (1977)

(Continued)

Table A3 (Continued)

Plant Scientific Name	Plant Common Name	Fungus Scientific Name	References
Poa trivialis	Rough-stalked meadow grass	Nonspecific	Read et al. (1976)
Saccharum	Sugarcane		
S. munja		*Endogone* sp.	Khan (1974)
S. officinarum	Sugarcane	Nonspecific	Phillips and Hayman (1970)
S. spontaneum		*Endogone* sp.	Khan (1974)
Scirpus nodosus	Bulrush	Nonspecific	Koske (1975)
Sieglingia decumbens	Heath-grass	Nonspecific	Read et al. (1976)
Sorghum	Sorghum	Nonspecific	Sieverding (1979)
		Glomus mosseae	Marx (1975)
S. bicolor		*G. fasciculatus*	Bagyaraj and Manjunath (1980)
S. bicolor var. *sudanense**	Sudan grass	*G. fasciculatum*	Hall and Armstrong (1979); Manjunath and Bagyaraj (1981); Manjunath et al. (1983)
S. sudanense	Sudan grass	Nonspecific	Ponder (1979), (1980)
		G. fasciculatus	Mehraveran (1977)
*S. vulgare**	Sudan grass	Nonspecific	Ratnayake et al. (1978)
		Gigaspora margarita	Carling and Brown (1980)
		Glomus constrictus	Daniels and Menge (1981)
		G. epigaeus	Daniels and Menge (1981)
		G. fasciculatus	Crush and Caradus (1980); Daniels and Menge (1981); Schwab et al. (1983)
		G. mosseae	Daniels and Menge (1981); Rao and Parvathi (1982)
Sporobolus arabicus	Drop-seed	*Endogone* sp.	Khan (1974)
Stenotaphrum secundatum	St. Augustine grass	Nonspecific	Koske (1975)
		E. calospora	Koske (1975)
		E. gigantea	Koske (1975)

(Continued)

Table A3 (Concluded)

Plant Scientific Name	Plant Common Name	Fungus Scientific Name	References
Stipa comata	Feathergrass	Nonspecific	Call (1981); Call and McKell (1982)
Triticum	Wheat	Nonspecific	Hayman (1980); Jensen and Jakobsen (1980); Strzemski (1974)
		Glomus macrocarpus	Swaminathan and Verma (1979)
*T. aestivum**	Spring wheat	Nonspecific	Schenck and Kellam (1978)
	Jubilar wheat	*Endogone* sp.	Jalali and Domsh (1975)
		G. fasciculatum	Larson et al. (1983)
		G. macrocarpum	
		G. microcarpum	
		G. mosseae	
Zea			
Z. diploperennis		Nonspecific	Scannerini and Bonfante-Fasolo (1983)
*Z. mays**	Corn, maize	Nonspecific	Hayman (1980); Howeler et al. (1982); Ocampo and Hayman (1980); Schawb and Reeves (1981)
		Acaulospora gerdemannii	Nicolson and Schenck (1979)
		A. trappei	Nicolson and Schenck (1979)
		Endogone sp.	Gerdemann (1974)
		G. constrictus	Daniels and Menge (1981)
		G. epigaeus	Daniels and Menge (1981)
		G. fasciculatus	Daniels and Menge (1981); Groth and Martinson (1983); Lindsey et al. (1977); Schawb and Reeves (1981)
		G. macrocarpus	Swaminathan and Verma (1979)
		G. mosseae	Covey et al. (1981); Daniels and Menge (1981); Groth and Martinson (1983); Lindsey et al. (1977); Marx (1975); Rao and Parvathi (1982); Schenck and Kellam (1978)

(Sheet 8 of 8)